MEMOIRS OF THE GEOLOGICAL SURVEY

ENGLAND AND WALES.

THE COALS OF SOUTH WALES.

WITH SPECIAL REFERENCE TO

THE ORIGIN AND DISTRIBUTION OF ANTHRACITE.

By AUBREY STRAHAN, M.A., Sc.D., LL.D., F.R.S.,
and W. POLLARD, M.A., D.Sc., F.I.C.

Assisted by E. G. RADLEY.

Second Edition.

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PREFACE
TO THE FIRST EDITION.

Preparations for this Memoir on the Coals of South Wales were commenced in 1901, when Sir Archibald Geikie was Director-General of the Geological Survey, and the collection of material has proceeded since that date, as circumstances allowed. Though obviously incomplete, in the sense that analyses might be multiplied indefinitely, the work had so far progressed in 1907 as to lead to a more or less definite opinion as to the relative distribution of anthracitic and bituminous coals, and as to the origin of the difference between them. The time appeared, therefore, to have arrived for publication of the results, though admittedly a larger number of analyses would add precision to the generalisations, and illustrate more fully certain seams and certain parts of the coalfield.

Necessarily there was much doubt at its inception what form the investigation should take. That each seam should be examined separately, and its modifications traced step by step from the bituminous into the anthracitic region, was clear. It was desirable also that all analyses should be made on a uniform system. For various reasons, explained in the following pages, it was impossible to follow fully so ideal a scheme. Samples of coal were not always procurable from the desired seam or locality, while a large number of analyses, the accuracy of which there was no reason to doubt, would have been inadmissible. Eventually it was decided that while special attention was being devoted to certain seams, opportunities ought not to be lost of getting specimens of others which happened to be accessible.

Difficulty arose also from the natural reluctance of the colliery proprietors to consent to the publication of coal-analyses over which they had had no control. This was overcome by the assistance kindly rendered by the South Wales Institute of Engineers. Not only was an arrangement made with the proprietors under which specimens could be collected and analyses published, but through Mr. Jones Price, Secretary to the Institute, we were kept informed where specimens could be procured.

This volume, which is the outcome of the investigation, has

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been written by Dr. Strahan and Dr. Pollard. The latter, with the assistance of Mr. E. G. Radley, has carried out all the chemical work, except some analyses which were made for the Geological Survey by Mr. C. A. Seyler. To Dr. Pollard also are due the chapters dealing with the methods of analysis, possible causes of error in analysis, and the classification of coals. The relation of carbon to hydrogen having proved to be the most reliable factor for expressing the character of the coal as regards anthracitism, the series of maps (forming Plates 3–7) were prepared to illustrate the distribution of anthracite on this basis. So far as we are aware, this is the first attempt to define the distribution of anthracite on purely experimental data.

Our thanks are due to Mr. Seyler for much assistance. He has not only furnished us with a large number of analyses, made independently of this investigation, but has given advice of great value in deciding on the method of analysis. We have also had the benefit of his comments on this volume during its passage through the press.

J. J. H. TEALL,
Director.

Geological Survey Office,
28, Jermyn Street, London,
17th February, 1908.

PREFACE
TO THE SECOND EDITION.

IN the preparation of a second edition of this Memoir, Dr. Pollard, who retired from the Geological Survey in 1913, has been so kind as to give his services. A large number of new analyses has been added, partly of samples collected by the Survey during a recent revision of some of the maps, and partly through the kindness of Mr. C. A. Seyler. The actual number of additional analyses is 118, and of these 15 were made by Mr. Radley under the supervision of Dr. Pollard before his retirement, 46 were of samples collected by the Survey but analysed by the Government Laboratory and 57 were by Mr. Seyler. The methods of analysis employed were in all cases such as to give strictly comparable results.

For facilities in collecting the new samples we are indebted to a large number of Colliery Proprietors and Officials, who in all cases cordially gave their assistance to our collectors. The same conditions as regards methods of collecting and the publication of the names of the collieries were observed as in 1908.

A consideration of the new data thus made available has rendered possible slight readjustments of the lines of isoanthracitisation shown on the charts, all tending towards greater precision in those spots where the evidence was defective. The result has been to confirm the general conclusions put forward in the first edition of the Memoir as to the distribution of the different varieties of coal, and to strengthen the arguments which were advanced that the differences are in the main original and not due to subsequent alteration.

A. STRAHAN,
Director.

Geological Survey Office,
28, Jermyn Street, London, S.W.,
30th April, 1915.

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WITH SPECIAL REFERENCE TO

THE ORIGIN AND DISTRIBUTION OF ANTHRACITE.

CHAPTER I.

HISTORICAL AND INTRODUCTORY.

By A. STRAHAN.

THE existence of anthracite in the South Wales coalfield was well known to the earliest miners of whom records exist, and the part of the coalfield to which anthracite was limited was roughly defined, so far as regards the small depths they were able to attain. Leland, for example, mentions that the coals of the Gwendraeth-fawr are anthracite (stone coals), while those of Llanelly are bituminous (ring coals).* The development of the coalfield, however, during the last 100 years has added much to the superficial observations first made, and has shown that the gradation into anthracite proceeds in accordance with certain general laws, the investigation of which seems likely to lead to results of both scientific and economic value.

The changes undergone by the coal present certain stages, which, though recognised commercially, are not capable of exact definition: from house-coal, or the most bituminous, the change is gradual into steam-coal, and from steam-coal into anthracite. The facts reported with respect to the changes are as follows:—

1st.—The anthracitic regions lie in the north-western corner of the Carmarthenshire, Brecknock, and Glamorganshire field, and in Pembrokeshire. In the former, which we may call the main coalfield, the seams become gradually less bituminous in approaching the anthracitic region. The change takes place from east to west along the north crop in the eastern end of the coalfield, from south-east to north-west nearer to Cardiff, and from south to north near Swansea and in the western part of the main coalfield. In other words, lines of equal anthracitisation circle round an area which extends from Kidwelly to Glyn Neath. In Pembrokeshire all the coal is anthracitic.

2nd.—The seams all show the change on approaching the anthracitic region, but the higher seams show it later than the

* "At *LLanelthle*, a Village of *Kidwelli* Lordship, a. vi. miles from *Kidwelli*, the Inhabitans digge Coles, elles scant in *Kidwelly* Land. Ther be ii. Maner of thes Coles. Ring Coles for Smith be blowid and waterid. Stones Colc be sumtime waterid, but never blowen. For blowing extinguishit them. So that *Vendwith Vaur* Coles be Stone Coles; *LLanethle* Coles Ring Colis."

("The Itinerary of John Leland the Antiquary," vol. 5. Published from the original Ms. in the Bodleian Library, by Thomas Hearne, M.A., *Oxford*, 1744.)

lower. Thus No. 2 Rhondda Coal keeps its character as a house-coal to within about 25 miles of the anthracitic centre, and then becomes a steam-coal. The house-coals, about 400 yards below, become steam-coals about 30 or 40 miles from the anthracitic centre, and then occur as anthracite for a distance of about 25 miles. It follows that in any one deep shaft the shallower seams should be more bituminous than the deeper, and this as a fact has been proved to be generally the case.

3rdly.—The loss of bituminous matter takes place at a more rapid rate in a south-to-north direction than in an east-to-west direction. This fact, taken in connection with the general form of the anthracitic region, so far as it has survived denudation, indicates that the original area of anthracitic coal was elongated in an east-and-west direction. It is obvious, moreover, that that area did not even approximately coincide with the existing coalfield, but lay, for the most part, outside it to the north and north-west.

There have been many speculations on the reasons for the diminution in bituminous matter. But while it was easy to find serious objection to every theory that had been advanced, the facts were not sufficiently definite to enable any fresh hypothesis to be put forward with confidence. A large number of analyses had been made, partly in connection with an official report written in 1848 by De la Beche and Playfair on "Coals suited to the Steam Navy," and partly for Dr. Percy for the purposes of his work on "Metallurgy." Of later years many analyses had been carried out by Mr. C. A. Seyler, to whom is due the credit of having taken the first steps towards a systematic classification of South Wales coals. Many others also had been furnished to colliery-proprietors by various analysts, but of these several were useless for the present purpose, some because the name of the seam was not given, others inasmuch as they were only proximate. Finally, a large series of analyses, including many of South Wales, had been collected in a useful publication by the Colliery Guardian Company.

It was clearly desirable, however, for the special purpose in view, that not only should all available analyses be collected and compared, but that all should be referred to their proper horizons in the Coal Measures, and that the series should be supplemented when necessary for the investigation of the change in character of any particular seam. Arrangements were commenced for the collecting and analysing of such further samples as might be required in January, 1901, by the sanction of Sir A. Geikie, at that time Director-General of the Geological Survey.

In view of the difficulty of knowing where a seam of which a specimen was required was at the moment being worked, and of obtaining the consent of the colliery-proprietors to fresh analyses being published, the advice of the South Wales Institute of Engineers was sought, with the result that on the 14th of January the Council appointed a Committee of the following gentlemen as being representative of every part of the coalfield:—The President (Mr. Thomas Evens), Messrs. Archibald Hood, H. K. Jordan, H. W. Martin, W. D. Wight, John

Roberts, Hugh Bramwell, Fox Tallis, W. Stewart, W. Forster Brown, James Barrow. Eventually the task of ascertaining in what localities specimens could be obtained, and of communicating with the colliery-proprietors, fell to the Secretary of the Institute, Mr. T. Jones Price, whose cordial co-operation in the work proved to be invaluable. It was arranged with the colliery-proprietors that the analyses might be published, but that the localities from which the samples were obtained should be indicated by numbers only on a general map of the coalfield, and that the names of the collieries should not be mentioned. These conditions have been complied with.

In selecting specimens with the special object in view of illustrating the progress of the change in the composition of the coal, it was obviously advisable to deal with each seam separately. It was useless, for example, to compare a seam high up in the Coal Measures in one locality with a seam near the base of the Coal Measures elsewhere. Specimens from the same seam, on the other hand, would be comparable in different localities, though they might be obtained from different depths below the surface. It seemed to be advisable, therefore, to select for the investigation a few of the more important seams, and especially those which could be recognised over wide areas. Subsequently difficulties arose in consequence of the selected seams not being accessible in regions from which specimens were desired, and from other causes, while at the same time, from a rigid adherence to this scheme, opportunities of getting specimens from other seams would have been lost. The bulk of the published analyses, moreover, could not have been utilised. While, therefore, the desirability of obtaining a series of analyses illustrative of the changes in any one seam was not lost sight of, analyses of other coals of local importance have been included in the lists.

The collecting was commenced in 1901. It was arranged that the collector should be conducted, at every colliery he visited, to a working face where a typical development of the seam was exhibited, and that coal should be cut by an official of the colliery from all parts of the face, except those partings which are separated out by the miners. The coal thus cut was sampled by the collector in the usual manner, and the sample was enclosed in a box with a printed form filled in by the colliery-manager, on which were given the name and section of the seam, depth from surface, and other particulars.

In 1908, when revision was made of Sheet 249, in preparation of a new edition of the Memoir on the Geology of the Country around Newport, the opportunity was taken to collect further samples (Nos. 204–218) from the collieries situated within that sheet. Similarly in 1913, when a new edition of the Memoir on the Geology of the Country around Pontypridd and Maestêg was in preparation, a collection of the samples Nos. 219–264 was made from that neighbourhood. The same arrangements as regards the collecting and the indication of localities were observed as in 1901.

CHAPTER II.

Sequence of the Seams.

By A. Strahan.

In view of the importance of considering the analyses of each seam separately, it becomes necessary to correlate, as far as possible, the seams of one part of the coalfield with those of another. In Plate 2 a series of vertical sections, ranging from the east to the west end of the coalfield, is arranged with the principal seam of the most productive belt of the measures as a datum-line. Above and below the datum-line the various seams referred to in the table of analyses are inserted in their proper respective positions, but the table does not profess to give a complete list of all the seams known to occur in South Wales.

The recognition of the seam selected as a datum-line may be regarded as fairly certain from Pontypool westwards so far as the Neath Valley along the North Crop. Its identification as the Nine Foot near Aberavan in the South Crop, and as the Stanllyd or Big Vein in the more western sections, is open to doubt. But though individual seams are difficult to identify, the productive belt as a whole is easily recognised. The identification of the principal seam in this belt as one and the same seam, while admittedly unproved, is put forward as the most probable, and as being certainly not far from the truth. The analyses of the seam thus selected are illustrated by the map forming Plate 4.

No individual correlation of the seams below the datum-line has been attempted. Locally some of them are valuable, but no one of them can be traced continuously over more than a small part of the coalfield. The analyses of these coals are grouped together in the map forming Plate 3.

The group of veins shown close above the datum-line in the five right-hand columns of Plate 2 yields the bulk of the best smokeless steam-coal of Glamorganshire. Though the veins are not everywhere individually recognisable the group persists along the northern and central parts of the coalfield from Pontypool to the Neath Valley. West of that valley and in the South Crop the seams in the corresponding position change greatly in number and thickness. The analyses of the veins belonging to this horizon are presented in the map forming Plate 5.

The identification of the seam known as the Tillery Vein in Monmouthshire, with that known as the No. 2 Rhondda or Brithdir Seam in Glamorganshire, and by other names in various parts of the coalfield, has been discussed in every succeeding Part of the Memoir on the South Wales Coalfield, and needs no further comment here. The analyses are shown on Plate 6.

The correlation of the Mynyddislwyn Vein with the Llantwit No. 3, the Wernffraith or Swansea Four Feet and the Box Big of Llanelly, is less capable of proof. Its correlation with the

Llantwit No. 3 has been adopted in accordance with arguments brought forward by Mr. H. K. Jordan* in preference to the correlation with Llantwit No. 1 which was originally selected. The reasons for identifying Llantwit No. 3 with the Wernffraith or Swansea Four Feet vein are explained in "The Country around Swansea" (*Mem. Geol. Survey*), 1907, pp. 33–35, but by some authorities the Graigola Vein of Swansea is regarded as the equivalent of the Mynyddislwyn. That the Wernffraith, Swansea Four Feet and Box Big are one and the same vein is generally admitted. The analyses of the Mynyddislwyn Vein and its supposed equivalents are inserted in Plate 7, together with those of some of the veins which occur between it and the No. 2 Rhondda seam.

Two facts are illustrated by the series of sections forming Plate 2. Firstly, that the measures expand rapidly from east to west, the thickness intervening between the Mynyddislwyn and the lowest seam at Pontypool being little more than a quarter of the thickness between the Box Big and the lowest seam near Llanelly. Secondly, that an expansion takes place also from north to south, the thickness near Aberavan in the South Crop being considerably greater than that in the North Crop on the same line of longitude. One exception to this rule is to be observed: locally, near Pontypool, there is a southerly and easterly attenuation, the smallest thickness known in any part of the coalfield being found near Cwm Bran. The greatest thickness on the other hand is reached in the south-west part of the coalfield, where no less than 5,700 feet intervene between the Box Big and the datum-line. Whether there is any connection between the varying thickness of the measures and the anthracitic character of the coal will be discussed in Chapter IX.

* *Proc. S. Wales Inst. Eng.*, vol. xxiii. (1903), pp. 190-204, 323-337.

CHAPTER III.

Analytical Methods and Table of Analyses.

By W. Pollard.

The methods of analysis employed for those analyses made in the Geological Survey Laboratory are given rather fully, as it is well known that variation in method in coal-analysis (especially in the determination of volatile matter) may produce variation in results. For the most part the methods are practically the same as those recommended by the Commission on Coal-analysis of the American Chemical Society.*

Sampling.—The samples as received at the laboratory are packed in large biscuit-tins enclosed in wooden boxes. The weight of the sample is 20 to 30 lbs. Usually it contains no large pieces, but all larger than a small orange are broken and the whole sample passed through a 1-in. sieve. After thorough mixing it is quartered in the usual way, the rejected half being at once replaced in the tin, whilst the other half is passed through a small Marsden-Blake crusher, and reduced by quartering to about 1 lb. This is then ground in a coffee-mill, set fine, halved and transferred to two stoppered bottles, the one for analysis, the other being tied down and sealed, in case it be required for future reference. The sample obtained by grinding in the coffee-mill is used for moisture and volatile matter estimations. For all other estimations a portion of this is further ground to pass the 50-hole sieve. The moisture is separately estimated in this sample also, so that all estimations can be calculated on coal as received. When coal analysis was first started in this laboratory volatile matter was determined on both samples, but as in no case were any great differences found, the determination on the fine (50-hole) sample was discontinued.

For the estimation of specific gravity a special sample is taken from the tin, and that portion only is used which passes an 8-hole and is retained on a 16-hole sieve. Moisture and ash are separately estimated on this sample in order to get the density of the dry coal, and an approximation to that of the pure coal.

Moisture.—This is estimated in all three samples. One gramme of coal is heated in a Victor-Meyer toluene bath for one hour exactly. The coal is weighed off between clipped watch-glasses, heated uncovered, covered immediately on removal from the toluene bath, and allowed to cool in a desiccator. It is weighed half an hour after removal from the bath. This method has been used in preference to that of drying *in vacuo* with sulphuric acid in a Hempel desiccator, as it is believed to be the more generally in use in other laboratories, although in many cases less moisture is found by this method. A discussion on this point is to be found in the *Journ. Am. Chem. Soc.* (*loc. cit.*).

Duplicate estimations should agree within ·1 per cent.

There seems no reason to recommend any change in the

* *Journ. Am. Chem. Soc.*, 1899, vol. xxi., p. 1,116.

method described (drying at 105° C. for one hour) unless it be that the drying should be carried out in a current of dry nitrogen or carbon dioxide, so as to prevent the possibility of the coal oxidising during the drying process. Some coals undoubtedly do oxidise in air at that temperature and will do so, though more slowly, even at ordinary temperatures. The use of well-fitting watch-glasses or shallow stoppered tubes (the upper glass or stopper is, of course, removed whilst drying) is important, as many coals are hygroscopic and rapidly gain weight on the balance after drying if left uncovered. These points are fully gone into in the Report of the International Committee on Analyses to the Eighth International Congress of Applied Chemistry at New York, 1912, p. 77 (Belin Frères, Paris, 1912).

Volatile Matter.—One gramme of coal is heated for seven minutes exactly in a platinum-crucible with well-fitting cover supported on a platinum-triangle over a bunsen giving a flame 20 cm. high. The bottom of the crucible should be 8 cm. above the mouth of the burner; gas-pressure should be 50 mm. of water. The particulars of the crucible used are:—Height, 40 mm.; diam. at base 24 mm., at top 34 mm. Capsule cover. A cylinder of clay or asbestos-board (of about 12 cm. diam.) should be used to prevent draughts from influencing the flame during the operation.

Loss in weight minus moisture gives volatile matter.*

Duplicates should agree within ·15 per cent. on coals, with 15 per cent. volatile matter and under, and ·30 per cent. on coals with over 15 per cent.

The value found for volatile matter depends to some extent on the size of crucible, tightness of cover, strength of flame, &c.; it is of importance therefore to work under as constant conditions as possible. With some coals at times a small explosion occurs after about one minute's heating, in which case the experiment should be discarded, otherwise too much volatile matter will be found. The cover of the crucible should fit so as to allow the egress of the volatile matter as easily as possible, but prevent the air from getting at the coke more than can be prevented. Meade and Attix† suggested heating a second time under identical conditions and subtracting the second loss from the first. This was tried in several cases, but did not appear to offer any distinct advantage over the other method.

Ash.—(See also under "Combustion.") The ash left in the platinum-boat after combustion has invariably been taken as representing the ash in the coal. Of all the constituents ash is probably the least accurately determinable (and hence oxygen also), a point that is gone into under "Accuracy of Coal Analyses" on page 38.

* Some analysts report as "Volatile Matter" all the loss including moisture, and as "Volatile Hydrocarbons" this loss minus moisture and half the sulphur. A short discussion and criticism on the different terms used in reporting proximate analyses will be found in "Analyses of British Coals and Coke," 1907, p. v. (The Chichester Press, London).

† *Journ. Am. Chem. Soc.*, 1899, vol. xxi., p. 1,137.

Duplicates should agree within ·1 per cent. on coals with less than 4 per cent. ash, and ·2 per cent. on coals with more than 4 per cent. ash.

Fixed Carbonaceous Residue.—This is obtained by subtracting the sum of the percentages of ash, moisture, and volatile matter from 100.

Total Sulphur.—The method of M. W. & J. Atkinson has been used with only slight modification. The following description of the method is taken from the report of the Commission on Coal Analysis of the American Chemical Society.*

"One gramme of finely-ground coke or coal is mixed thoroughly with 5 grammes of dry sodium carbonate, spread evenly over the bottom of a flat or shallow platinum dish, and the latter placed on a rectangular rest made of clay pipe-stems inside a muffle, which though hot is still black. The temperature of the muffle should be raised gradually during half an hour to clear cherry-redness, and then kept at the latter temperature for 10 to 15 minutes. The sodium carbonate should not sinter or fuse. The mass should not be stirred. When the carbon is burned, usually in about 45 minutes in all, cool, digest with 100 to 200 c.c. of warm water, allow to settle, decant through a filter and wash twice by decantation, and then on the filter, adding a few drops of a solution of sodium chloride if the residue tends to pass through the filter. The filtrate is acidified with 12 c.c. concentrated hydrochloric acid, and precipitated with barium chloride."

To avoid any possibility of all the sulphur not being oxidised to sulphate before acidifying, a little (about 10 c.c.) bromine water has always been added after filtering and before acidifying. It is usually necessary to heat for longer than the 45 minutes to burn off all the carbon. With these slight differences the method has been adhered to with most satisfactory results. The muffles used have been Fletcher gas-muffles, Nos. 461 and 661. Blind experiments have always been made simultaneously with and separately from determinations of sulphur in coal, and in no case has any appreciable amount of sulphur been obtained from the gas. As it is almost invariably necessary to correct for traces of sulphur contained in the sodium carbonate used, it is always as well to make a blind experiment with each batch of sulphur-estimations.

Duplicates should agree within ·1 per cent.

For a discussion on determination of sulphur in coal reference should be made to a paper by Dr. M. Hollinger in *Z. Angew. Chem.*, xxi. (1909), pp. 436, 493. Brunck's cobalt-oxide method is there recommended for total sulphur, and a modification of Sauer's method for combustible sulphur. The original method as described above has been adhered to in our recent analyses to secure uniformity with the previous work. No opportunity has occurred of carrying out comparative tests of Atkinson's method and that recommended by Dr. Hollinger.

* *Ib.*, p. 1,116. The original appeared in the *Journ. Chem. Ind.*, 1886.

Sulphur in Ash.—This is obtained from the ash from the combustion. The ash is transferred to a dish, hydrochloric acid added, evaporated to dryness, taken up with hydrochloric acid and hot water, filtered, and the sulphur in the filtrate precipitated with barium chloride. The amount of sulphur obtained here, subtracted from the total sulphur, gives the Combustible Sulphur.

Nitrogen.—Estimated by Kjeldahl's method. 1 gramme of coal is heated with 20 c.c. strong sulphuric acid, 8 grammes dry potassium sulphate and a bead of mercury, till colourless. Allow to cool, pour into a flask of about 1,000 c.c. capacity containing about 200 c.c. water, rinse out, etc., and add 80 c.c. of a 50 per cent. sodium hydrate solution and 20 c.c. of a 5 per cent. potassium-sulphide solution. Distil (using a good splash-head), collecting in 20 c.c. $\frac{N}{10}$ acid. Titrate back with $\frac{N}{10}$ alkali, using methyl orange as indicator.

The mercury, and hence the potassium sulphide, may be dispensed with,* the only difference apparently being that with the mercury shorter heating is needed. Blind experiments should be made and the correction applied. Duplicates should agree within ·1 per cent.

In the recent analyses made in the Government Laboratory a slight modification tending to greater accuracy was adopted in carrying out the nitrogen determination. The details of the method as actually employed were as follows:—

To I gramme of coal 30 c.c. of pure concentrated sulphuric acid containing 1 gramme of salicylic acid were added, the vessel being kept cool by immersion in water during the addition of the acid. Five grammes of sodium thiosulphate were then added cautiously, and afterwards 7 grammes of potassium sulphate and a crystal of copper sulphate. The mixture was then heated, cautiously at first to avoid frothing, and then strongly until all the coal was decomposed. The solution was then cooled and distilled with excess of soda and a little sodium sulphide in the usual way into 25 c.c. of $\frac{N}{10}$ sulphuric acid.

The excess of soda was determined by adding to the solution 10 c.c. of a 10 per cent. solution of potassium iodide and 5 c.c. of a saturated solution of potassium iodate—the liberated iodine was determined as usual. A sharper end-point was obtained by this method than by that formerly used. Duplicate determinations agreed to within 0·05 per cent.

Combustion.—(Carbon, hydrogen and ash.) Jena-glass combustion-tubes, about 110 cm. long and 12–15 mm. internal diameter, are best used. They are filled as follows:—

10 cm. space at each end.
6 to 8 cm. copper-oxide roll.
16 to 20 cm. space for boat.
45 cm. copper-oxide.
8 cm. lead-chromate pumice.
10 cm. silver spiral.

* Lunge. "Chem. Techn. Untersuchungsmethoden," 4th ed., vol. i., p. 228.

The furnace should be about 36 inches long; that used in this laboratory is a Fletcher combustion-furnace No. 2. The boat is of platinum, 10 cm. long. The purifying train (one for air and one for oxygen with a three-way tap so that the gas can be changed at once) consists of an Emmerling's absorption-tube and a washbottle with 1 in 2 potash, one washbottle with concentrated sulphuric acid, followed by two U-tubes filled with pumice saturated with concentrated sulphuric acid.* Between the three-way tap and the combustion-tube a small sulphuric acid washbottle is placed (so that the rapidity of the gas-current can be easily watched), followed by a small mercury-trap. For the collection of the water a U-tube filled with pumice saturated with sulphuric acid is used. Before each combustion this is filled with acid overnight, the acid being drained off just before weighing. Geissler bulbs, with an 8 cm. drying-tube filled with freshly-crushed potash, are used to absorb the carbonic acid, followed by a small sulphuric acid U-tube to absorb the last traces of moisture, and finally a protecting tube of sulphuric acid pumice. It is hardly necessary to state that bulbs and tubes are refilled before each combustion.

The following points may be of use, although it is unnecessary to describe the combustion in detail. The weight of dry coal is as near ·5 gramme as possible, this having been found the most convenient amount to work with for accuracy. The finely powdered coal (50-hole sample) should be used, and spread in as thin a layer as possible in the boat. The boat and coal should be dried for one hour exactly in the toluene bath immediately before required. When the boat, after final weighing before combustion, is placed in the combustion-tube, it should rest on a strip of platinum-foil; this prevents any chance of its sticking to the tube, and diminishes the chance of any copper oxide adhering to it. Before commencing to heat the boat the oxygen is turned on in a gentle current. The copper oxide and silver spiral should be at a bright-red heat, and the copper oxide roll and lead chromate pumice a dull red heat. When these are at the required temperature the boat is gradually heated and the combustion carried out in the usual way.

Duplicates should agree within:—

Hydrogen	·1 per cent.
Carbon	·2 „

It is important for the copper oxide to be hot enough before the coal is heated, as possibly methane is amongst the first of the volatile products to come off, and it is well known that this gas requires a high temperature for combustion. In two of the earlier combustions made in this laboratory there seemed some reason to suspect that some methane had escaped combustion, as the difference between the carbon and hydrogen of the lower to the higher results gave the ratios of $C:H = 1:3·5$ and $C:H = 1:3·8$, whilst in each case the ash agreed. On repeating these combustions concordant results with the higher values were

* The pumice should be ignited with sulphuric acid before use to expel chlorides, etc.

obtained in each case. Another possible source of error, when duplicates agree in the hydrogen but not in the carbon and ash, may be due to incomplete combustion of the carbon. This was found to have occurred on more than one occasion, in each case the coal containing over 5 per cent. of ash, and having a high caking-power. It was, indeed, owing to this that a boat 10 cm. long has since been used instead of one of the usual size, as the half gramme of coal can be spread out into a thin layer, thus reducing the chance of incomplete combustion. The following example illustrates this point. A boat 5 cm. long was used, and the caking power of the coal was about 45:—

—	1	2	3
C.	79·72	79·97	80·13
H.	4·75	4·76	4·82
Ash	8·38	8·12	7·98

The hydrogens all agree within the limit of ·1 per cent., but the carbons vary. Nos. 2 and 3 are within the ·2 limit, but No. 1 is low. On looking at the ashes, however, it will be seen that the sum of ash and carbon is in each case the same.

It has been suggested that one cause of low carbon-results might be due to some carbon monoxide escaping complete combustion to dioxide. At Mr. Seyler's suggestion a small wash-bottle, containing dilute sodium-palladium chloride solution, was placed behind the protecting U-tube, so that all gases from the combustion-tube, not previously absorbed by the U-tube and potash-bulbs, must pass through the solution, and thus render it possible to detect monoxide. On no occasion has there been any indication whatever of its presence, in spite of one or two low carbons which could not be accounted for, except by assuming a slight leak between U-tube and potash-bulbs, though none could be detected.

Although several papers have appeared suggesting modifications in carrying out combustions since the first edition of this Memoir was written, there is no reason to believe that more accurate results combined with rapidity of working can be obtained than by the method originally adopted.

Caking Power.—This determination is not capable of any great accuracy, but is sometimes of use for comparative purposes. The coal is powdered to pass the 50-hole sieve, and is mixed with varying proportions of dry sand, which passes the 40-hole and stops on the 50-hole sieve; the weight of the two together is 25 grammes for each experiment. The charge is placed in a platinum-crucible, and heated exactly as for an estimation of volatile matter. After cooling, the cake is carefully removed from the crucible, placed on a flat surface, and a 500-gramme weight carefully placed on it. When the cake *just* crushes the caking-power is reached. The caking power is expressed as the weight of sand per unit weight of coal, thus:—

Sand.	Coal.	Caking Power.
20·0	5·0	4
22·5	2·5	9
24·0	1·0	24 etc.

It is important that the coal be as fresh from the pit as possible, as in many cases the caking-power has been found to decrease by keeping.

Specific Gravity.—Estimated in a specific-gravity bottle, on about 5 grammes of the special sample already described. Air is removed by boiling. Moisture- and ash-determinations are specially made on this sample, so as to give data for calculating approximately the density of the dry ash-free coal.

To correct for ash, either ·01 may be deducted from the specific gravity for each per cent. of ash, or the specific gravity of the ash may be specially estimated and correction applied. In either case, the final result of correcting can only be regarded as approximate.

In the analyses made at the Government Laboratory the specific gravity determinations were carried out at 15·5° C., using 150 grains of coal and a pyknometer holding 1,000 grains. The air was removed by evacuating the pyknometer, and check-determinations were made by boiling in the manner described above.

As an example of a possible error in the correction, where the specific gravity of the ash has been determined:—If the specific gravity of a coal containing 95 per cent. of pure coal and 5 per cent. pyrites (moisture and other ash-constituents are omitted for the sake of simplicity) be 1·300, taking the specific gravity of pyrites as 5·0, the specific gravity of the pure coal would be 1·251. But as 5 per cent. pyrites would become on ashing (assuming the reaction to be quantitative) 3·33 per cent. Fe_2O_3, and taking the specific gravity of Fe_2O_3 as 5·1, the specific gravity of the pure coal as found would be 1·268. As it happens, in this case the deduction of ·01 for each per cent. of ash would be the nearer, but in the case where the ash as obtained by analysis is the same as that really contained in the coal, the direct method would probably give the more accurate figure.

Analyses of the Coals of South Wales, from all Sources.

Abbreviations.

Geol. Surv.—Samples collected and analysed by the Geological Survey in the years 1901-9.

G.S. (C. A. S.)—Samples collected by the Geological Survey, but analysed by Mr. C. A. Seyler in the year 1905.

Gov. Lab.—Samples collected by the Geological Survey but analysed at the Government Laboratory in the year 1914.

Adm. Rept.—" Report on the Coals suited to the Steam Navy," by Sir H. T. de la Beche and Dr. Lyon Playfair. 1st Rep., dated 1848; 2nd Rep., 1849; 3rd Rep., 1851. The first Report was printed in *Mem. Geol. Survey*, vol. ii., Part 2, pp. 539-630, 1848.

Percy, 37, p. 325.—" Metallurgy," by John Percy, M.D., F.R.S., F.G.S., Ed. 1875. The first number refers to the number of the analysis, the second to the page.

S.W. Inst. E.—Transactions and Proceedings of the South Wales Institute of Engineers.

C.G.—*Colliery Guardian.*

A.B.C. and C.—" Analyses of British Coals and Cokes collected and compared." Reprinted from the *Colliery Guardian.* (First issue in parts, not dated; 2nd issue in 1907.)

Inst. M.E.—Transactions of the Federated Institution of Mining Engineers.

Inst. C.E.—Proceedings of the Institution of Civil Engineers.

C.A.S.—Analyses made and communicated to the Geological Survey by Mr. C. A. Seyler.

Per C.A.B.—Analyses communicated to the Geological Survey by Mr. Capel A. Branfill.

The carbon, hydrogen, oxygen and nitrogen are expressed in percentages calculated for the " pure coal," *i.e.* for the coal after deduction for moisture, ash, and combustible sulphur. Thus in analysis 1, C. 88·66 + H. 4·89 + O. 4·90 + N. 1·55=100.

The $\frac{C}{H}$ ratio is the relation of carbon to hydrogen. Thus in Analysis 1, $\frac{88{\cdot}66}{4{\cdot}89} = 18{\cdot}13$.

The percentage of volatile matter is calculated on the coal exclusive of moisture and ash.

The fuel-ratio is the relation of fixed carbonaceous residue to volatile matter. Thus in Analysis 1, $\frac{100-30{\cdot}80}{30{\cdot}80} = 2{\cdot}25$.

The specific gravity is determined on the coal as received from the colliery.

The ash is expressed in percentage of the dry coal, *i.e.* coal dried at 105°C.

No. on Plates 1 and 3-7.	1-inch Map.	Local Name of Vein.	Colliery.	Authority.
1	232	Black	... ...	Geological Survey ...
2	249	"	... ...	" " ...
3	232	Top Coal, Rock	... ...	" " ...
4	249	Black	... ...	" " ...
5	248	Nine Foot ...	... ...	" " ...
6	231	Nine Foot ...	... ...	" " ...
7	232	Ras-las ...	... ...	" " ...
8	232	Rock or Horn	... ...	" " ...
9	248	Nine Foot ...	... ...	" (C.A.S.) ...
10	229	Big	... ...	" " ...
11	230	Stanllyd ...	... ...	" " ...
12	229	Big	... ...	" " ...
13	229	Stanllyd ...	... ...	" " ...
14	231	Big	... ...	" " ...
15	247	Four Foot ...	... ...	" " ...
16	230	Big	... ...	" " ...
17	230	Stanllyd ...	... ...	" " ...
18	248	Cribbwr ...	... ...	" " ...
19	231	Nine Foot ...	... ...	" " ...
20	249	Cwm Frood Rock	Near Varteg Iron Co.'s Works	Adm. Rept. i., pp. 33, 62
21	231	Gadley Nine Foot	One-third mile W. of Aberdare	Adm. Rept. ii., pp. 35, 54
22*	231	Ras-las ...	Dowlais ...	Percy, 37, p. 325 ...
23	248	Nine Foot ...	Llynfi	Percy, 73, p. 332 ...
24	231	Nine Foot ...	Bute Pit, Hirwain	Percy, 83, p. 332 ...
25	231	Nine Foot ...	Pwllfaron, Glyn Neath	Percy, 95, p. 333 ...
26	231	Big	Gwaunclawdd	S.W. Inst. E., xxi, p. 503
27	247	Nine Foot ...	Morfa	S.W. Inst. E., xxi, p. 519, No. 422
28	249	Black	Abercarn ...	S.W. Inst. E., xxi, p. 519, No. 224
29	230	Big	... ...	C.A.S. ... ...
30	230	Big	... ...	" ... ...
31	230	Big	... ...	" ... ...
32	230	Big	... ...	" ... ...
33	230	Stanllyd Big ...	... ...	" ... ...
34	230	Big or Nine Foot	Pontyberem ...	C.G., lxx, p. 1,212, and lxxxiv, p. 1,081
35	249	Black	Tirpentwys Coal Co.	A.B.C. & C. (1907), p. 131
36	232	Black	Llanhilleth ...	A.B.C. & C. (1907), p. 129
37	231	Big	Ynyscedwyn ...	Inst. M.E., xx (1900-1), p. 159
38	230	Middle Vein, Lower Stanllyd	... ...	C.A.S. ... ...
39	232	Big	Blaina ...	Percy, 8, p. 322 ...
40	231	Big	Abercraf ...	A.B.C. & C. (1st Ed.), p. 126

* See note (1) at end of Table.

No. on Plates 1 and 3-7.	C.	H.	O.	N.	C/H ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
1	88·66	4·89	4·90	1·55	18·13	30·80	2·25	1·33	6·4
2	88·24	5·24	4·92	1·60	16·84	34·41	1·91	1·31	5·3
3	88·30	5·45	4·83	1·42	16·20	36·10	1·77	1·33	7·1
4	87·49	5·33	5·76	1·42	16·41	36·50	1·74	1·335	6·8
5	91·58	4·51	2·36	1·55	20·30	17·87	4·60	1·34	2·8
6	93·15	3·59	1·89	1·37	25·95	11·59	7·63	1·41	3·8
7	91·64	4·30	2·74	1·32	21·31	16·65	5·00	1·365	4·7
8	88·61	5·29	4·80	1·30	16·75	33·03	2·03	1·303	3·9
9	91·40	4·78	2·62	1·20	19·12	17·56	4·69	1·33	3·2
10	93·86	3·44	1·50	1·20	27·28	5·67	16·64	1·392	2·1
11	94·37	3·49	·98	1·16	27·04	5·42	17·46	1·440	2·7
12	93·77	3·74	1·26	1·23	25·07	6·47	14·46	1·409	2·4
13	94·43	3·33	1·27	·97	28·36	5·30	17·84	1·434	1·1
14	93·56	3·57	1·68	1·19	26·21	5·90	15·95	1·437	3·9
15	88·51	5·02	5·24	1·23	17·63	28·08	2·56	1·315	2·3
16	94·19	3·43	1·18	1·20	27·61	5·30	17·87	1·431	1·9
17	94·06	3·47	1·26	1·21	27·11	5·71	16·52	1·444	3·6
18	87·93	5·39	5·06	1·62	16·31	29·86	2·35	1·288	·9
19	92·65	3·96	1·98	1·41	23·40	8·52	10·74	1·435	6·2
20	88·65	6·29	3·86	1·20	14·09	33·20	2·01	1·255	6·0
21	91·89	4·59	2·38	1·16	20·02	14·22	6·03	1·333	5·3
22	90·87	4·65	3·03	1·45	19·54	—	—	—	2·0
23	91·37	4·93	3·70		18·53	20·05	3·99	—	2·4
24	93·62	4·11	2·27		22·78	10·02	8·98	—	1·8
25	93·79	3·86	2·35		24·30	6·25	15·00	—	2·0
26	93·37	3·43	3·20		27·22	5·40	17·52	—	2·2
27	86·30	5·34	8·35		16·16	30·40	2·29	—	5·5
28	86·19	5·41	8·40		15·93	31·40	2·18	—	—
29	93·92	3·55	2·53		26·49	5·00	19·00	—	1·6
30	93·70	3·63	2·67		25·81	5·17	18·34	—	1·0
31	93·86	3·83	2·31		24·51	5·76	16·36	—	2·0
32	93·96	3·74	2·30		25·12	5·50	17·18	—	1·2
33	94·21	3·75	2·04		25·12	5·75	16·39	—	1·8
34	95·33	3·47	1·20		27·47	—	—	—	1·1
35	90·74	4·84	3·43	·99	18·73	—	—	1·34	5·3
36	86·85	4·77	7·28	1·10	18·21	—	—	—	2·2
37	93·21	3·57	3·22		26·11	8·50	10·76	—	1·6
38	93·82	3·81	2·37		24·62	5·83	16·15	—	—
39	87·14	6·49	4·81	1·56	13·43	—	—	—	4·0
40	93·91	3·70	2·39		25·38	6·08	15·44	—	2·0

No. on Plates 1 and 3–7.	1-inch map.	Local Name of Vein.	Colliery.	Authority.
41	231	Big	Ystradgynlais...	A.B.C. & C. (1st Ed.), p. 123
42	248	Yard	Aberaman ...	C.G., lxxi., p. 541 ...
43	247	Average of Four and Six Foot	Llanmorlais ...	„ p. 1,015 ...
44	230	Stanllyd ...	Park and Blaina	A.B.C. & C. (Ed. 1907), p. 367
45	232	Old	... ...	Geological Survey ...
46	232	Old or Lower Four Foot	Nantyglo and Blaina	Percy, 122, p. 569 ...
47	231	Peacock ...	... ...	C.A.S. ... ...
48	230	Little [Brass]	... ...	„ ... ...
49	230	Peacock ...	... ...	„ ... ...
50	230	Brass	Cwmllynfell ...	Adm. Rept., i., pp. 34 & 58
51	230	Peacock ...	... ...	C.A.S. ... ...
52	231	Peacock ...	Gwaunclawdd	A.B.C. & C. (1st Ed.), p. 123
53	230	Peacock ...	... ...	C.A.S. ... ...
54	248	No. 2 Rhondda	... ...	S.W. Inst. E., xxi, p. 511
55	248	Rock Vawr ...	Bronbil ...	Adm. Rept., ii., pp. 21 & 51
56	248	No. 2 Rhondda	... ...	C.A.S. ... ...
57	249	Rock	Machen ...	Adm. Rept., iii., pp. 39 & 51
58	248	No. 2 Rhondda	... ...	C.A.S. ... ...
59	248	Rock Fawr ...	Bronbil ...	Adm. Rept., iii, pp. 43 & 52
60	230	Upper or Pen-y-Graig	Cwm Clic ...	Percy, 130, p. 569 ...
61	248	No. 2 Rhondda-	Glyn Corwg ...	Percy, [the mean of] 118–120, p. 569
62	247	Penlan Gas-coal	Penlan... ...	A.B.C. & C. (1st Ed.), p. 82
63	232	Meadow ...	... ...	Geological Survey ...
64	232	Mynydd Black	Blaenserchan ...	A.B.C. & C. (Ed. 1907), p. 129
65	232	Meadow ...	... ...	Geological Survey ...
66	247	Cribbwr ...	Morfa	S.W. Inst. E., xxi, p. 516.
67	231	Four Foot or Cornish	Abercraf ...	A.B.C. & C. (1st Ed.), p. 126
68	231	Cornish ...	Pwllfaron ...	Percy, 121, p. 569 ...
69	247	Four Foot ...	Morfa	S.W. Inst. E., xxi, p. 519.
70	230	Wernffraith ...	Primrose ...	C.G., lxxi, p. 1,015 ...

No. on Plates 1 and 3-7.	C.	H.	O.	N.	C/H ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
41	93·88	3·65	1·85	·62	25·72	—	—	—	2·1
42	—	—	—	—	—	10·73	8·32	—	2·4
43	—	—	—	—	—	24·00	3·17	—	2·0
44	94·32	3·68	2·00		25·63	5·15	18·42	—	1·1
45	87·93	5·30	5·50	1·27	16·59	31·48	2·18	1·320	5·0
46	90·74	5·23	4·03		17·35	22·72	3·40	—	6·0
47	94·02	3·96	2·30		23·74	7·20	12·88	—	2·4
48	94·19	3·58	2·23		26·31	5·12	18·53	—	1·6
49	93·67	3·73	2·60		25·11	5·84	16·12	—	1·4
50	93·60	3·54	2·64	·22	26·44	7·21	12·87	1·375	1·5
51	93·39	3·66	2·95		25·52	5·25	18·04	—	1·8
52	93·70	3·90	2·40		24·03	6·34	14·76	—	2·3
53	94·02	3·66	2·32		25·69	5·76	16·36	—	2·2
54	89·74	5·67	4·59		15·83	27·60	2·62	—	—
55	85·23	4·80	9·35	·62	17·76	40·56	1·47	1·292	7·5
56	91·78	5·13	3·19		17·89	18·31	4·47	—	6·4
57	75·00	5·15	18·85	1·00	14·56	36·19	1·76	1·297	3·8
58	92·64	4·74	2·62		19·54	17·33	4·77	—	6·6
59	84·78	5·57	8·94	·71	15·22	43·26	1·31	1·301	4·3
60	93·58	4·05	2·37		23·11	7·62	12·12	—	5·3
61	91·66	4·85	3·49		18·91	19·55	4·12	—	4·5
62	—	—	—	—	—	33·50	2·13	1·257	2·1
63	87·97	5·26	5·25	1·52	16·72	34·34	1·91	1·330	8·1
64	87·52	5·16	6·26	1·06	16·96	—	—	—	3·1
65	87·16	5·42	5·83	1·59	16·08	33·84	1·95	1·326	6·5
66	87·50	5·15	7·35		16·99	28·90	2·46	—	1·3
67	93·69	3·74	2·57		25·05	6·73	13·85	—	2·0
68	93·83	3·95	2·22		23·75	6·78	13·75	—	4·1
69	85·20	5·40	9·40		15·78	30·60	2·27	—	2·6
70	92·45	4·80	2·75		19·26	—	—	—	3·0

No. on Plates 1 and 3-7.	1-inch map.	Local Name of Vein.	Colliery.	Authority.
71	247	Four Foot ...	Near Morriston	Adm. Rept., i., pp. 32 & 60
72	249	Mynyddislwyn	... ...	Geological Survey ...
73	249	Bedwas Vein ...	Bedwas ...	Adm. Rept., i., pp. 40 & 63
74	247	Five Foot ...	Mynydd-Newydd	S.W. Inst. E., xxi, p. 508
75	247	Penyfilia or Five Foot	,, ,,	Adm. Rept., i, pp. 29 & 61
76	247	Clyndie [Clyn-du] or Five Foot	Llangyfelach ...	Adm. Rept., i, pp. 24 & 61
77	231	Six Foot ...	Glyncastle ...	Inst. M.E., xii, p. 238; also A.B.C. & C. (Ed. 1907), p. 386
78	248	Two-foot-nine	Blaen Rhondda	Percy, 98, p. 333 ...
79	248	,, ,,	Dunraven ...	Percy, 101, p. 333 ...
80*	231	Gadley Four Foot	1-3rd mile w. of Aberdare	Adm. Rept., ii, p. 35 & 53
81	248	Upper Four Foot	Ffaldau ...	S.W. Inst. E., xxi, p. 508; C.G., lxx, p. 639
82	248	,, ,,	Ynysyfaio ...	C.G., lxxv, p. 570, and lxxxiv, p. 1,081
83	248	,, ,,	Dunraven ...	Percy, 102, p. 333 ...
84	248	,, ,,	Blaen Rhondda	Percy, 99, p. 333 ...
85†	231	,, ,,	Dowlais ...	Percy, 36, p. 325 ...
86	248	Four Foot of Dyffryn	Aberdare Valley	Adm. Rept., i, pp. 25 & 61
87	232	Four Foot ...	Ebbw Vale Iron-works	Adm. Rept., i, pp. 42 & 64
88	231	,, ,, ...	Hill's Plymouth Merthyr	Adm. Rept., ii, pp. 42 & 65
89	248	Upper Four Foot	Aberaman ...	Adm. Rept., iii, pp. 26 & 49
90	232	Ell	Blaina ...	Percy, 6, p. 322 ...
91	230	Graigola ...	Primrose ...	C. G., lxxi, p. 1,015 ...
92	232	Three Quarter	Blaina ...	Percy, 7, p. 322 ...
93	232	Three Quarter (top vein)	Nantyglo and Blaina	Percy, 123, p. 569 ...
94	249	Three Quarter	... ...	Geol. Surv. ... ...
95	232	Three Quarter Rock	Nr. Varteg Iron Co.'s Works	Adm. Rept., i, pp. 30 & 62
96	232	Three Quarter	... ...	Geol. Surv. ... ...
97	232	,, ,,	... ...	,, ...
98	230	Six Feet ...	Graigola Merthyr	C. G., lxxi, p. 1,015 ...
99	230	Six Feet ...	Primrose ...	S.W. Inst. E., xxi, p. 508
100	247	Six Feet (part of)	Mynydd-Newydd	S.W. Inst. E., xxi, p. 513

* See note (1) at end of Table. † See note (2) at end of Table.

No. on Plates 1 and 3-7.	C.	H.	O.	N.	$\frac{C}{H}$ ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
71	91·81	4·66	3·34	·19	19·70	18·10	4·53	1·31	3·4
72	86·94	5·64	5·84	1·58	15·41	37·52	1·66	1·336	7·3
73	90·01	6·71	1·67	1·61	13·41	30·41	2·29	1·32	6·9
74	91·66	4·87	3·47		18·82	18·80	4·32	—	6·4
75	88·66	6·03	3·68	1·63	14·70	26·04	2·84	1·31	3·2
76	91·18	3·97	4·85	trace	22·97	15·97	5·26	1·358	6·1
77	93·63	4·01	1·91	·45	23·35	—	—	—	1·3
78	94·11	4·19	1·70		22·46	11·03	8·06	—	2·8
79	93·35	4·15	2·50		22·49	11·16	7·96	—	1·4
80	93·77	4·64	·65	·94	20·21	11·22	7·91	1·327	4·9
81	91·31	4·95	3·74		18·45	18·78	4·33	1·29	·9
82	—	—	—	—	—	12·02	7·32	—	1·0
83	91·86	3·93	4·21		23·37	10·61	8·42	—	3·8
84	92·74	3·96	3·30		23·42	10·26	8·75	—	4·8
85	90·92	4·51	3·31	1·26	20·16	—	—	—	1·2
86	92·93	4·91	·63	1·53	18·93	16·23	5·16	1·326	3·3
87	92·10	5·28	·40	2·22	17·44	22·84	3·38	1·275	1·5
88	91·44	4·13	3·95	·48	22·14	18·19	4·50	1·359	2·4
89	93·40	4·39	·97	1·24	21·27	15·22	5·57	1·305	1·5
90	84·42	5·48	8·41	1·69	15·41	—	—	—	1·5
91	92·73	4·64	2·63		19·98	—	—	—	4·7
92	86·25	5·90	6·13	1·72	14·62	—	—	—	2·5
93	89·81	5·11	5·08		17·58	25·03	2·99	—	4·2
94	87·81	5·09	5·64	1·46	17·25	32·39	2·09	1·314	6·2
95	87·19	5·72	5·85	1·24	15·24	42·12	1·37	1·34	11·0
96	86·63	5·13	6·85	1·39	16·89	33·92	1·95	1·307	4·6
97	87·20	5·10	6·36	1·34	17·10	32·78	2·05	1·327	7·0
98	—	—	—	—	—	12·53	6·98	—	1·7
99	91·70	4·80	3·50		19·10	15·70	5·37	—	4·6
100	90·75	4·73	4·52		19·19	20·30	3·93	—	6·0

No. on Plates 1 and 3-7.	1-inch map.	Local Name of Vein.	Colliery.	Authority.
101	247	Binea or Loughor Fiery	Binea Farm ...	Adm. Rept., i, pp. 28 & 59
102	247	Brynddwey ...	Neath Abbey	Adm. Rept., ii, pp. 13 & 50
103	230	Graigola ...	Ynysymond ...	Adm. Rept., i, pp. 31 & 57
104*	247	Ward's Fiery ...	1½ miles E. of Llanelly	Adm. Rept., i, pp. 27 & 58
105	246	Fiery	Old Castle ...	Adm. Rept., i, pp. 26 & 58
106	247	Graigola ...	Birchgrove ...	Adm. Rept., iii, pp. 21 & 48
107	247	Brynddwey ...	Neath	Inst. C.E., viii, p. 101
108	230	Graigola ...	Waun-y-coed ...	Percy, 89, p. 333 ...
109	232	Red	... ...	Geol. Surv. ... ...
110	232	Big	... ...	" ... ...
111	249	"	Tirpentwys ...	A. B. C. & C. (Ed. 1907), p. 132
112	230	Tregloin ...	... ...	C.A.S. ... ...
113†	230	" ...	... ...	" ... ...
114	247	Cadoxton ...	Cadoxton ...	Adm. Rept., iii, pp. 16 & 47
115	247	Hughes ...	... ...	C.A.S. ... ...
116	247	Slatog	Weigfawr ...	S.W. Inst. E., xxi, p. 523
117	247	Rotten or Bodor	" ...	S.W. Inst. E., xxi, p. 519
118	247	Curly	" ...	S.W. Inst. E., xxi, p. 519
119	247	Hedley's ...	Cwrt-y-Bettws	S.W. Inst. E., xxi, p. 508
120	247	Hughes ...	" "	C.G., lxxi, p. 1,015 ...
121	247	" ...	Weigfawr ...	S.W. Inst. E., xxi, p. 523
122	247	Three Foot ...	Mynydd-Newydd	S.W. Inst. E., xxi, p. 508
123‡	249	Charcoal ...	Abercarn ...	Adm. Rept., iii, pp. 33 & 50
124	230	Lower or Welsh	Cwm Clic ...	Percy, 131, p. 569 ...
125	248	No. 3 Rhondda	Penrhiw ...	A.B.C. & C. (Ed. 1907), p. 392
126	248	Graig	Dunraven ...	Percy, 100, p. 333 ...
127	248	Graig	Blaen Rhondda	Percy, 97, p. 333 ...
128§	230	Red	Pwllbach ...	S.W. Inst. E., xxi, p. 506
129	231	"	Dillwyn ...	A.B.C. & C. (Ed. 1907), p. 390)

* See note (4) at end of Table. † See note (5) at end of Table.
‡ See note (6) at end of Table. § See note (7) at end of Table.

No. on Plates 1 and 3-7.	C.	H.	O.	N.	C/H ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
101	92·61	4·84	1·06	1·49	19·13	12·39	7·08	1·304	4·0
102	93·57	5·31	—	1·12	17·62	40·00	1·50	1·310	3·6
103	88·12	3·99	7·46	·43	22·09	14·99	5·67	1·30	3·2
104	94·68	4·23	—	1·09	22·38	—	—	1·344	7·0
105	90·14	5·03	3·48	1·35	17·92	20·77	3·82	1·289	2·6
106	88·96	4·38	5·89	·77	20·31	15·59	5·41	1·360	4·4
107	85·33	5·32	7·66	1·69	16·04	—	—	—	5·1
108	93·08	4·47	2·45		20·82	13·96	6·16	—	1·9
109	87·77	4·97	5·94	1·32	17·66	31·08	2·22	1·325	3·4
110	87·81	5·12	5·65	1·42	17·15	32·97	2·03	1·338	7·2
111	90·58	5·39	3·39	·64	16·81	—	—	1·319	5·0
112	94·16	3·66	2·18		25·73	5·20	18·23	—	2·0
113	93·79	3·63	2·58		25·84	5·41	17·48	—	4·3 1·3
114	92·64	4·58	1·67	1·11	20·23	18·67	4·36	1·378	3·6
115	92·46	4·36	3·18		21·16	11·74	7·52	—	2·2
116	83·63	5·28	11·09		15·84	35·70	1·80	—	4·4
117	85·69	5·81	8·50		14·75	33·60	1·97	—	3·3
118	85·93	5·92	8·15		14·52	37·70	1·65	—	5·5
119	91·69	4·59	3·72		19·98	14·75	5·77	—	4·4
120	91·52	4·71	3·77		19·43	—	—	—	4·0
121	77·40	4·67	17·93		16·57	51·50	·94	—	27·5
122	91·46	5·02	3·49		18·22	19·70	4·08	—	4·1
123	84·56	6·57	8·07	·80	12·87	32·26	2·10	1·334	2·0
124	93·71	3·69	2·60		25·40	7·44	12·44	—	4·4
125	88·44	5·32	5·11	1·13	16·62	25·40	2·94	—	1·6
126	91·66	4·71	3·63		19·46	19·61	4·10	—	3·4
127	92·57	4·72	2·71		19·61	16·35	5·12	—	3·3
128	92·48	4·03	3·49		22·95	6·04	15·56	—	1·7 5·5
129	93·56	3·48	2·21	·75	26·89	—	—	—	3·9

No. on Plates 1 and 3-7.	1-inch map.	Local Name of Vein.	Colliery.	Authority.
130	230	Red	... ...	C.A.S. ... ...
131	230	,, ...	Cwm Gors ...	A.B.C. & C. (Ed. 1907), p. 403
132	230	,, ...	... ...	C.A.S. ... ...
133	230	,, ...	Cawdor ...	S.W. Inst. E., xxi, p.506
134	230	,, ...	Ynysygeinon ...	S.W. Inst. E.,xxi, p. 506
135	230	,, ...	... ...	C.A.S. ... ...
136	230	Pontyberem No. 1 [Gras-uchaf]	Pontyberem ...	A.B.C. & C. (1st Ed.), p. 58
137	230	Clynhebog ... [Lower Pumpquart]	,, ...	A.B.C. & C. (1st Ed.), p. 58
138	230	Middle... ...	... ...	C.A.S. ... ...
139	230	Lower	... ...	,, ...
140	230	Lower Trichwart	... ...	,, ...
141	230	New Cross Hands [Lower Pumpquart]	New Cross Hands	A.B.C. & C. (1st Ed.), p. 83
142	230	Lower Pumpquart	... ...	C.A.S. ... ...
143	230	,, ,,	... ...	,, ...
144	229	Big	... ...	,, ...
145	229	Drap	... ...	,, ...
146	229	Green	... ...	,, ...
147	248	Cae David ...	Ty-chwyth ...	Percy, 72, p. 332 ...
148	248	Six Foot ...	Dunraven ...	Percy, 103, p. 333 ...
149	248	,, ...	Llynfi	Percy, 74, p. 332 ...
150	248	Duffryn ...	,, ...	Percy, 75, p. 332 ...
151	248	Yard	,, ...	Percy, 77, p. 332 ...
152	247	Five Foot (top)	... ...	Geol. Surv. ... ...
153	247	,, (middle)	... ...	,, ...
154	247	,, (bottom)	... ...	,, ...
155	247	,, (top ...	... ...	,, ...
156	247	,, (middle)	... ...	,, ...
157	247	,, (bottom)	... ...	,, ...
158	247	,, (top ...	... ...	,, ...
159	247	,, (middle)	... ...	,, ...
160	247	,, (bottom)	... ...	,, ...
161	230	Peacock ...	Brynhenllys ...	Per C.A.B. ... ...
162	231	Big	Ynyscedwyn ...	,, ...
163	230	Peacock ...	Gilfach ...	,, ...
164	231	Red	Dillwyn ...	,, ...
165	230	Big	Gwauncaegurwen	,, ...
166	230	Peacock ...	,, ,,	,, ...
167	230	Big	Garnant ...	,, ...

No. on Plates 1 and 3-7.	C.	H.	O.	N.	$\frac{C}{H}$ ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
130	93·03	3·51	3·46		26·50	7·73	11·94	—	3·6
131	94·08	3·79	2·13		24·85	6·48	14·43	—	2·7
132	93·39	4·09	2·52		22·83	7·39	12·53	—	1·9
133	93·42	4·02	2·56		23·24	6·50	14·38	—	2·8
134	92·58	3·91	3·50		23·68	7·70	11·98	—	3·0
135	93·33	3·93	2·74		23·75	6·53	14·31	—	2·0
136	—	—	—		—	5·39	17·54	—	1·7
137	—	—	—		—	5·54	17·04	—	·9
138	94·31	3·64	2·05		25·91	5·24	18·08	—	1·7
139	94·09	3·58	2·33		26·28	5·12	18·53	—	1·7
140	94·1	3·6	2·3		26·14	5·10	18·61	—	2·6
141	93·87	3·41	2·72		27·53	3·83	25·1	—	·8
142	93·00	3·68	3·32		25·27	5·20	18·28	—	1·1
143	94·38	3·14	1·16	·87	30·06	5·17	18·19	—	·8
144	93·83	3·74	2·43		25·09	6·72	13·87	—	1·4 3·3
145	92·59	4·54	1·30	1·57	20·39	—	—	—	1·4
146	93·98	3·88	2·14		24·22	6·71	13·90	—	2·4
147	87·99	5·64	6·37		15·60	34·35	1·91	—	4·2
148	92·73	3·95	3·32		23·48	12·03	7·31	—	3·0
149	91·25	4·84	3·91		18·85	20·17	3·96	—	2·0
150	89·75	4·92	5·33		18·24	23·33	3·29	—	3·9
151	90·53	4·98	4·49		18·18	23·17	3·32	—	2·6
152	92·65	4·45	1·30	1·60	20·81	17·63	4·67	1·365	6·4
153	90·58	4·33	3·61	1·48	20·89	19·55	4·12	1·358	6·1
154	91·49	4·45	2·49	1·57	20·58	17·75	4·63	1·332	5·1
155	90·91	4·79	2·70	1·60	18·98	22·71	3·40	1·337	6·2
156	88·64	4·72	5·00	1·64	18·77	27·21	2·67	1·365	8·4
157	89·98	4·82	3·54	1·66	18·67	23·62	3·23	1·321	5·2
158	92·40	4·38	2·04	1·18	21·10	16·47	5·07	1·369	5·9
159	91·36	4·32	2·73	1·59	21·15	17·70	4·65	1·365	5·7
160	90·48	4·34	3·66	1·52	20·85	15·99	5·25	1·353	5·6
161	92·13	3·76	4·11		24·54	—	—	—	1·4
162	92·46	3·20	4·34		28·87	—	—	—	1·6
163	93·92	3·57	2·51		26·26	—	—	—	1·0
164	93·42	3·39	1·65	1·54	27·54	9·00	10·11	—	1·8
165	94·49	3·67	1·84		25·77	—	—	—	1·7
166	93·80	3·16	3·04		29·64	—	—	—	2·3
167	93·17	2·12	4·71		43·85*	—	—	—	·4

* See footnote on p. 63.

No. on Plates 1 and 3-7.	1-inch map.	Local Name of Vein.	Colliery.	Authority.
168	231	Peacock ...	International ...	Per C. A. B. ... ...
169	231	Big	,, ...	,, ...
170	230	Stanllyd ...	Caerbryn ...	,, ...
171	231	Big	Onllwyn ...	,, ...
172	231	,, ...	Abercraf ...	,, ...
173	231	Eighteen Foot	Pwllfaron ...	Percy, 96, p. 333 ...
174	249	Black	Glyn	A.B.C. & C. (Ed. 1907), p. 124
175	230	Big	Blaencaegurwen	Per C.A.B. ... ...
176	231	Four Foot ...	Ystradgynlais...	,, ...
177	228	Lower Level and Kilgetty	Bonville's Court and Kilgetty	Per C.A.B. and A.B.C. & C.(Ed. 1907), p. 404
178	229	Big	Carway ...	A.B.C. & C. (Ed. 1907), p. 369
179	249	Brithdir ...	... ...	Geol. Surv. ... ...
180	232	Mynyddislwyn	... ...	,, ...
181	232	Tillery ...	... ...	,, ...
182	232	Red Ash ...	... ...	,, ...
183	247	Five Foot (top)	... ...	C.A.S. ... ...
184	247	,, (middle)	... ...	,, ...
185	247	,, (bottom)	... ...	,, ...
186	247	Four Foot (top)	... ...	,, ...
187	247	,, (bottom)	... ...	,, ...
188	249	Black	Celynen ...	A.B.C. & C. (Ed. 1907), p. 127
189	249	Three Quarter	Tirpentwys ...	A.B.C. & C. (Ed. 1907), p. 132
190	229	Green Vein ...	Cae Pontbren...	A.B.C. & C. (Ed. 1907), p. 368
191	230	Peacock ...	Garnant ...	A.B.C. & C. (Ed. 1907), pp. 369 & 370
192	230	Stanllyd and Pumpquart	Emlyn ...	A.B.C. & C. (Ed. 1907), p. 371
193	247	Yankee ...	Clyne Valley ...	A.B.C. & C. (Ed. 1907), p. 382
194	247	Three Foot ...	,, ...	A.B.C. & C. (Ed. 1907), p. 384
195	247	[Box Big] ...	Glan Mwrwg ...	A.B.C. & C. (Ed. 1907), p. 391
196	248	Forest ...	Penrhiw ...	A.B.C. & C. (Ed. 1907), p. 392
197	247	Lynch ...	Lynch	A.B.C. & C. (Ed. 1907), p. 394
198	228	Timber ...	Hill Pit, Hook	A.B.C. & C. (Ed. 1907), p. 405

No. on Plates 1 and 3-7.	C.	H.	O.	N.	$\frac{C}{H}$ ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
168	93·73	3·22	3·05		29·12	—	—	—	1·8
169	95·15	2·11	2·74		45·07*	—	—	—	2·3
170	93·20	3·12	2·74	·94	29·90	—	—	—	·7
171	—	—	—	—	—	5·48	17·26	—	1·2
172	93·16	3·52	3·32		26·43	—	—	—	1·4
173	93·52	3·82	2·62		24·48	7·02	13·25	—	3·6
174	—	—	—		—	36·78	2·16	—	2·5
175	93·13	2·17	4·70		42·97*	—	—	—	·7
176	91·81	3·99	4·20		23·00	—	—	—	1·7
177	95·68	3·04	·51	·77	31·50	—	—	—	1·0
178	93·72	3·68	2·60		25·54	5·89	15·97	—	1·6
179	89·73	5·71	2·88	1·68	15·71	28·69	2·49	1·37	10·5
180	87·66	6·09	4·38	1·87	14·39	33·14	2·02	1·334	5·2
181	87·87	6·01	4·67	1·45	14·62	35·25	1·84	1·346	5·3
182	88·33	5·79	4·27	1·61	15·26	32·79	2·05	1·313	3·5
183	92·55	4·88	2·57		18·95	14·82	5·75	—	7·2
184	91·26	4·56	4·18		20·0	16·26	5·15	—	7·2
185	92·70	4·44	2·86		20·9	12·96	6·72	—	5·7
186	91·54	4·62	3·84		19·8	14·96	5·69	—	2·2
187	92·52	4·78	2·70		19·4	15·37	5·51	—	12·3
188	89·27	5·60	3·44	1·69	15·93	25·84	2·87	—	4·3
189	89·64	4·37	4·99	1·00	20·51	—	—	—	5·0
190	94·37	3·69	1·94		25·57	—	—	—	1·4
191	93·94	3·77	2·29		24·93	6·10	15·38	—	1·8
192	93·31	3·02	2·52	1·15	30·91	—	—	—	1·5
193	88·12	5·57	6·31		15·82	30·81	2·24	—	2·3
194	87·22	5·49	7·29		15·87	31·26	2·20	—	4·3
195	—	—	—	—	—	15·43	5·48	—	4·4
196	86·38	5·37	6·97	1·28	16·07	—	—	—	1·8
197	—	—	—	—	—	26·93	2·71	—	2·4
198	94·72	3·25	2·03		29·12	4·74	20·1	—	·8

* See footnote on p. 63.

No. on Plates 1 and 3-7.	1-inch map.	Local Name of Vein.	Colliery.	Authority.
199	228	Bonville's Court	... ...	C.A.S. ... ...
200	228	,, ,,	Reynalton ...	A.B.C. & C. (Ed. 1907), p. 404
201	230	Little Vein ...	Little VeinSlant, Ammanford	A.B.C. & C. (Ed. 1907), p. 367
202	248	Cae David ...	Llynfi	Percy, 76, p. 332 ...
203	247	Four Foot ...	Clyne Valley ...	A.B.C. & C. (Ed. 1907), p. 383
204	249	Brithdir ...	... ...	Geol. Surv. ... ...
205	,,	Ras-las ...	... ...	,, ...
206	,,	,, ...	... ...	,, ...
207	,,	Nine Foot ...	... ...	,, ...
208	,,	Tillery ...	... ...	,, ...
209	,,	Black	... ...	,, ...
210	,,	,, ...	... ...	,, ...
211	,,	Nine Foot ...	... ...	,, ...
212	,,	,, ...	... ...	,, ...
213	,,	Mynyddislwyn	... ...	,, ...
214	,,	Brithdir ...	... ...	,, ...
215	,,	Big	... ...	,, ...
216	,,	Nine Foot ...	... ...	,, ...
217	,,	Mynyddislwyn	... ...	,, ...
218	,,	Black	... ...	,, ...
219	248	Two-foot-nine	... ...	Gov. Lab. ... ...
220	,,	Lantern ...	... ...	,, ...
221	,,	No. 2 Rhondda	... ...	,, ...
222	,,	Lantern ...	... ...	,, ...
223	,,	No. 3 Rhondda	... ...	,, ...
224	,,	Rock fawr ...	... ...	,, ...
225	,,	No. 2 Rhondda	... ...	,, ...
226	,,	Lower New ...	... ...	,, ...
227	,,	Victoria ...	... ...	,, ...
228	,,	Wernddu or No. 2 Rhondda	... ...	,, ...
229	,,	Wernddu ...	... ...	,, ...
230	,,	No. 2 Rhondda	... ...	,, ...
231	,,	,, ...	... ...	,, ...
232	,,	Rock-fawr ...	... ...	,, ...
233	,,	,, ...	... ...	,, ...
234	,,	Forest-fach ...	... ...	,, ...
235	,,	Nine Foot ...	... ...	,, ...
236	,,	No. 2 Rhondda	... ...	,, ...
237	,,	,,	... ...	,, ...
238	,,	Nine Foot or Ras Las	... ...	,, ...
239	,,	No. 3 Rhondda	... ...	,, ...
240	,,	,, ...	... ...	,, ...
241	,,	Nine Foot, Red Coal	... ...	,, ...
242	,,	No. 2 Rhondda	... ...	,, ...
243	,,	No. 3 Rhondda	... ...	,, ...
244	,,	Nine Foot ...	... ...	,, ...
245	,,	Six Foot ...	... ...	,, ...
246	,,	No. 2 Rhondda	... ...	,, ...

No. on Plates 1 and 3-7.	C.	H.	O.	N.	C/H ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
199	93·26	3·28	3·46		28·43	—	—	—	—
200	—	—	—		—	5·89	15·99	—	1·1
201	94·36	3·63	2·01		26·02	—	—	—	1·5
202	90·78	5·13	4·09		17·69	24·74	3·04	—	5·4
203	88·80	5·36	5·84		16·55	30·30	2·31	—	2·6
204	90·08	5·21	3·08	1·63	17·27	28·15	2·55	1·373	10·2
205	91·85	4·57	2·02	1·56	20·11	18·78	4·32	1·385	5·1
206	91·77	4·52	2·18	1·53	20·31	17·77	4·63	1·342	3·9
207	90·86	4·88	2·79	1·47	18·60	25·62	2·90	1·348	4·75
208	86·23	5·53	6·54	1·65	15·59	38·42	1·60	1·333	4·3
209	86·62	5·10	6·72	1·56	16·98	36·52	1·74	1·379	8·1
210	88·08	5·15	5·25	1·52	17·09	34·57	1·89	1·331	5·06
211	91·73	4·29	2·36	1·62	21·39	16·53	5·05	1·357	4·3
212	89·79	5·03	3·83	1·35	17·86	27·76	2·60	1·377	8·4
213	88·30	5·29	4·60	1·81	16·70	30·60	2·77	1·318	3·8
214	89·23	5·27	3·92	1·58	16·94	30·10	2·32	1·344	5·8
215	87·17	5·16	6·29	1·38	16·90	35·05	1·85	1·345	6·1
216	90·36	4·86	3·25	1·53	18·60	23·64	3·23	1·328	4·1
217	86·61	5·54	5·98	1·87	15·63	37·56	1·66	1·311	3·3
218	88·41	5·21	4·79	1·59	16·97	32·82	2·05	1·330	5·6
219	90·86	4·59	2·99	1·56	19·80	20·97	3·77	1·306	5·02
220	85·02	5·32	8·02	1·64	16·00	39·52	1·53	1·289	14·64
221	85·37	5·18	7·86	1·59	16·48	38·00	1·63	1·311	5·25
222	84·50	5·26	8·63	1·61	16·00	37·22	1·67	1·299	4·98
223	87·17	5·54	5·67	1·62	15·75	37·00	1·70	1·281	6·92
224	85·15	5·05	8·13	1·67	16·86	38·07	1·63	1·296	3·25
225	87·83	5·11	5·39	1·67	17·20	35·15	1·84	1·308	16·17
226	91·65	4·37	2·50	1·48	20·97	18·49	4·41	1·315	3·14
227	92·33	4·46	1·77	1·44	20·70	21·22	3·72	1·323	7·86
228	90·12	5·01	3·36	1·51	17·98	23·56	3·24	1·299	7·61
229	89·39	4·94	4·12	1·55	18·10	27·59	2·62	1·292	3·75
230	91·66	4·43	2·50	1·41	20·71	16·46	5·05	1·317	4·75
231	91·66	4·66	2·20	1·48	19·66	21·09	3·98	1·312	6·42
232	84·27	5·12	8·93	1·68	16·46	39·92	1·51	1·323	6·25
233	84·45	5·23	8·65	1·67	16·14	37·59	1·67	1·309	3·67
234	89·93	4·91	3·83	1·33	18·31	25·92	2·86	1·284	4·92
235	91·43	4·61	2·44	1·52	19·83	19·39	4·15	1·302	5·70
236	91·43	4·80	2·23	1·54	19·04	23·10	3·34	1·310	6·58
237	87·40	5·50	5·28	1·82	15·89	35·86	1·80	1·315	11·94
238	91·92	4·15	2·57	1·36	22·15	13·65	6·33	1·319	3·40
239	88·67	5·38	4·38	1·57	16·43	35·64	1·81	1·281	8·50
240	91·86	4·79	2·06	1·29	19·19	21·03	3·76	1·305	4·66
241	90·66	4·79	3·03	1·52	18·92	22·03	3·54	1·305	7·47
242	88·43	5·24	4·69	1·64	16·88	32·25	2·10	1·285	4·74
243	88·59	5·10	4·63	1·68	17·36	29·68	2·38	1·278	2·65
244	91·03	4·54	2·99	1·44	20·04	16·88	4·92	1·292	4·34
245	90·99	4·58	2·94	1·49	19·86	19·50	4·13	1·303	4·04
246	88·59	5·50	4·34	1·57	16·10	29·05	2·45	1·283	5·57

No. on Plates I and 3–7.	1-inch map.	Local Name of Vein.	Colliery.	Authority.
247	248	Red	... ...	Gov. Lab. ... ...
248	,,	Six Foot ...	... ...	,, ...
249	,,	Nine Foot ...	... ...	,, ...
250	,,	Six Foot ...	... ...	,, ...
251	,,	Red	... ...	,, ...
252	,,	Six Foot ...	... ...	,, ...
253	,,	,, ...	... ...	,, ...
254	,,	Nine Foot ...	... ...	,, ...
255	,,	Four Foot ...	... ...	,, ...
256	,,	No. 2 Rhondda	... ...	,, ...
257	,,	Nine Foot ...	... ...	,, ...
258	,,	,, ...	... ...	,, ...
259	,,	Four Foot ...	... ...	,, ...
260	,,	Six Foot ...	... ...	,, ...
261	249	Nine Foot ...	... ...	,, ...
262	,,	Six Foot ...	... ...	,, ...
263	,,	Four Foot ...	... ...	,, ...
264	248	Six Foot ...	... ...	,, ...
265	231	Four Foot ...	... ...	C.A.S. ... ...
266	229	Green	... ...	,, ...
267	229	Big	... ...	,, ...
268	231	Brass	... ...	,, ...
269	230	Middle ...	... ...	,, ...
270	230	Red	... ...	,, ...
271	230	Pumpquart ...	... ...	,, ...
272	231	Peacock ...	... ...	,, ...
273	230	Stanllyd ...	... ...	,, ...
274	232	Deep Black ...	... ...	,, ...
275	230	? ...	... ...	,, ...
276	248	Werntarw ...	... ...	,, ...
277	247	New	... ...	,, ...
278	232	Deep Black (top)	... ...	,, ...
279	,,	,, (middle)	... ...	,, ...
280	,,	,, (bottom)	... ...	,, ...
281	247	Four Foot ...	... ...	,, ...
282	,,	Five Foot ...	... ...	,, ...
283	230	Four Foot ...	... ...	,, ...
284	,,	Golden... ...	... ...	,, ...
285	230, 231	No. 2	... ...	,, ...
286	?	Big	... ...	,, ...
287	?	,, ...	... ...	,, ...
288	229	Yard	... ...	,, ...
289	228	?	... ...	,, ...
290	231	Lower	... ...	,, ...
291	231	Gnapiog ...	... ...	,, ...
292	230	Stanllyd Big ...	... ...	,, ...
293	230	Stanllyd ...	... ...	,, ...
294	231	Blaenant ...	... ...	,, ...
295	230	Two Foot Nine	... ...	,, ...
296	230	Peacock ...	... ...	,, ...
297	230	Big	... ...	,, ...
298	230	Red	... ...	,, ...
299	228	Rock	... ...	,, ...

No. on Plates 1 and 3-7.	C.	H.	O.	N.	$\frac{C}{H}$ ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
247	90·72	4·70	3·12	1·46	19·29	18·82	4·31	1·291	4·75
248	90·13	4·44	3·96	1·47	20·30	16·85	4·94	1·319	5·61
249	91·13	4·49	2·86	1·52	20·30	16·32	5·13	1·316	4·50
250	91·17	4·54	2·77	1·52	20·07	18·22	4·49	1·304	3·16
251	91·80	4·31	2·54	1·35	21·29	14·37	5·92	1·277	5·54
252	91·32	4·28	3·01	1·39	21·34	15·27	5·56	1·328	5·40
253	91·33	4·23	3·01	1·43	21·59	15·37	5·51	1·337	5·17
254	91·64	4·34	2·47	1·55	21·09	14·01	6·14	1·305	4·07
255	91·79	4·31	2·60	1·30	21·29	14·41	5·94	1·303	5·97
256	89·32	5·09	3·74	1·85	17·54	27·21	2·64	1·287	5·94
257	91·42	4·24	2·82	1·52	21·56	15·31	5·53	1·296	3·14
258	91·79	4·38	2·19	1·64	20·96	14·69	5·81	1·304	2·79
259	92·00	4·34	2·44	1·22	21·19	14·58	5·85	1·313	3·89
260	91·65	4·45	2·14	1·76	20·59	15·69	5·37	1·304	3·41
261	92·11	4·19	2·19	1·51	21·98	13·80	6·24	1·313	3·55
262	92·04	4·15	2·55	1·26	22·18	13·56	6·38	1·311	3·48
263	91·74	4·26	2·80	1·20	21·51	14·86	5·73	1·326	4·82
264	89·80	4·59	4·03	1·58	19·56	21·28	3·70	1·330	4·72
265	93·52	4·08	2·41		22·92	8·76	10·41	—	4·48
266	94·08	3·51	3·41		26·80	6·50	14·38	—	3·98
267	93·90	3·57	2·53		26·30	6·35	14·75	—	1·70
268	93·88	3·73	2·39		25·17	6·45	14·50	—	1·64
269	93·78	3·62	2·60		25·90	5·74	16·42	—	1·66
270	93·99	3·67	2·34		25·61	6·83	13·64	—	4·54
271	94·81	3·45	1·74		27·48	7·94	19·24	—	2·94
272	93·90	3·68	2·42		27·58	6·25	15·00	—	1·66
273	94·00	3·56	2·44		26·40	5·81	16·06	—	1·33
274	87·76	5·27	6·97		16·65	32·91	2·04	—	9·58
275	92·61	4·39	3·00		21·09	16·31	5·13	—	5·00
276	85·33	5·64	9·03		15·13	40·07	1·47	—	10·50
277	87·83	5·70	6·47		15·41	38·18	1·62	—	8·90
278	85·95	5·46	8·59		15·74	36·59	1·73	—	11·52
279	85·49	5·63	8·88		15·18	37·88	1·64	—	8·38
280	86·62	5·60	7·78		15·40	36·08	1·77	—	11·60
281	91·54	4·34	4·12		21·09	15·64	5·39	—	5·10
282	90·82	4·28	4·90		21·22	19·45	4·14	—	10·74
283	91·37	4·49	4·14		20·35	15·88	5·30	—	7·60
284	93·16	4·17	2·67		22·34	11·73	7·52	—	3·80
285	93·02	4·19	2·79		22·20	9·97	9·03	—	2·64
286	93·56	3·52	2·92		26·58	6·52	14·33	—	5·80
287	93·83	3·49	2·68		26·88	5·72	16·48	—	—
288	94·17	3·78	2·05		24·91	7·34	12·62	—	1·24
289	94·88	3·38	1·74		28·07	5·58	16·92	—	3·18
290	94·52	3·51	1·97		26·93	6·15	15·26	—	2·90
291	93·93	3·65	2·42		25·74	6·30	14·87	—	2·40
292	93·47	3·62	2·91		25·82	6·26	14·97	—	1·86
293	94·46	3·51	2·03		26·91	6·78	13·75	—	5·00
294	93·27	4·27	2·46		21·84	12·52	6·99	—	3·66
295	93·83	3·52	2·65		26·65	6·54	14·29	—	2·78
296	94·44	3·42	2·14		27·61	5·75	16·39	—	1·86
297	94·29	3·42	2·29		27·57	5·85	16·09	—	2·00
298	93·92	3·70	2·38		25·38	6·79	13·73	—	2·00
299	95·09	3·28	1·63		28·99	4·75	20·05	—	2·20

No. on Plates 1 and 3-7.	1-inch map.	Local Name of Vein.	Colliery.	Authority.
300	230	Rock (top) ...	... ...	C.A.S. ... ...
301	230	,, (middle)	... ...	,, ...
302	230	,, (bottom)	... ...	,, ...
303	230	Charcoal ...	... ...	,, ...
304	230	Three Foot One	... ...	,, ...
305	230	East Pit Big ...	... ...	,, ...
306	231	Three Foot ...	... ...	,, ...
307	231	Nine Foot ...	... ...	,, ...
308	,,	,, ...	... ...	,, ...
309	228	? ...	... ...	,, ...
310	231	Eighteen Foot	... ...	,, ...
311	230	Stanllyd ...	... ...	,, ...
312	230	Lower Pump-quart.	... ...	,, ...
313	230	Triquart ...	... ...	,, ...
314	248	,, (top) ...	... ...	,, ...
315	,,	,, (middle)	... ...	,, ...
316	,,	,, (lower)	... ...	,, ...
317	,,	,, (bottom)	... ...	,, ...
318	230	Triquart ...	... ...	,, ...
319	?	Braslyd ...	... ...	,, ...
320	230	Red	... ...	,, ...
321	228	?	... ...	,, ...

NOTES.

(1) No. 22.—The figures for Pure Coal as given in Percy are incorrect. The figures here given have been obtained by recalculating from "Composition per cent., exclusive of water only."

(2) No. 80—The analysis here quoted is recalculated from the figures of "Gadly Four-Feet Seam," as given on p. 57 of the second Adm. Rept. under Analysis 1. Analysis 2 adds up to 100·97, thus giving no oxygen in the coal.

(3) No. 85.—See Note (1).

(4) No. 104.—The N, as given on p. 12 of Adm. Rept. 1, should read 1·02 (as on p. 59). The analysis adds up to 100·69, but a note on p. 58 states "The pure coal contained only 3·82 per cent. ash." There is obviously something wrong with the oxygen and ash, but this would not affect the C/H ratio, though rendering the analysis as calculated to "Pure Coal" doubtful.

(5) No. 113.—The figures given represent the mean of two different specimens. The greatest difference on the Pure Coal was ·01 in the C and ·08 in the H. The percentage of ash in both specimens is, however, given.

(6) No. 123.—The analyses as given on pp. 5 and 55 differ in O (9·76 and 9·96). In both cases the analyses add up to over 100 (102·00 and 102·20). As the O is obtained by difference, the figure should read 7·76. This value, therefore, has been taken.

(7) No. 128.—A similar case to No. 113—see Note (5).

No. on Plates 1 and 3-7.	C.	H.	O.	N.	$\frac{C}{H}$ ratio.	Volatile Matter.	Fuel-ratio.	Sp. Gr.	Ash.
300	93·99	3·62	2·39		25·96	6·80	13·70	—	3·14
301	94·88	3·64	1·48		26·07	7·25	12·79	—	8·92
302	93·54	3·67	2·79		25·49	7·38	12·55	—	9·40
303	94·24	3·28	2·48		28·73	5·45	17·35	—	1·12
304	94·25	3·54	2·21		26·62	6·32	14·82	—	2·80
305	94·03	3·44	2·53		27·33	6·62	14·10	—	2·60
306	93·25	3·86	2·89		24·16	7·53	12·28	—	3·40
307	93·83	3·81	2·36		24·63	7·23	12·83	—	3·20
308	93·67	3·81	2·52		24·58	7·25	12·79	—	1·20
309	94·36	3·03	2·61		31·14	8·59	10·64	—	17·40
310	94·12	3·83	2·05		24·57	7·32	19·16	—	3·58
311	94·09	3·48	2·43		27·04	5·19	18·27	—	·80
312	94·31	3·35	2·34		28·15	5·09	18·64	—	1·00
313	94·16	3·45	2·39		27·30	5·46	17·31	—	3·04
314	91·99	4·32	3·69		21·29	15·21	5·57	—	3·00
315	92·07	4·65	3·28		19·80	18·13	4·52	—	7·80
316	92·03	4·40	3·57		20·91	14·68	5·81	—	2·40
317	92·38	4·35	3·27		20·93	14·48	5·91	—	4·40
318	94·41	3·36	2·23		28·10	5·80	16·24	—	6·92
319	93·32	3·65	3·02		25·57	6·96	13·37	—	3·30
320	93·22	3·85	2·92		24·21	8·78	10·43	—	2·80
321	94·30	3·29	2·40		28·66	5·50	17·81	—	2·82

Calorific Values.—These were determined in the Government Laboratory for the coals there analysed, namely, Nos. 219–264.

Report by the Government Laboratory.

The gross calorific value was determined on coal ground to pass through a 50-hole sieve, in a bomb-calorimeter (Mahler-Kroeker's type), suitable corrections being applied for radiation. The results of duplicate determinations were, as a rule, within 20 calories on about 8,000 calories per gram of coal.

The net calorific value refers to the above-mentioned value after allowing for the condensation of steam.

The calorific values calculated from the composition of the coal were obtained by the use of the following formulæ for the heat of combustion of carbon, hydrogen and sulphur:—

(1) $8080 \times C + 34460\,(H - \frac{1}{8}O) + 2250 \times S.$
(2) $8080\,(C - \frac{3}{8}O) + 34460 \times H + 2250 \times S.$

These formulæ are intended to allow to some extent for the different state of combination of the oxygen in the coal. Where both calculated values are appreciably less than the experimental values, this is probably to be accounted for by the presence of sulphur in the form of pyrites.

No. on Plates 1 and 3-7.	Determined Calorific value (gross).	Net Calorific value.	Calculated Calories.		Moisture.
			$C+(H-\frac{1}{8}O)+S$	$(C-\frac{3}{8}O)+H+S$.	
219	8,254	7,994	8,271	8,308	0·53
220	7,016	6,754	6,996	7,082	1·56
221	7,674	7,355	7,643	7,730	2·35
222	7,726	7,424	7,663	7,762	2·00
223	7,916	7,598	7,944	8,014	1·16
224	7,931	7,623	7,750	7,852	2·11
225	7,009	6,647	6,910	6,957	1·69
226	8,433	8,168	8,431	8,473	0·61
227	7,977	7,609	7,851	7,875	0·74
228	8,014	7,728	8,044	8,078	0·89
229	8,271	7,984	8,270	8,318	1·22
230	8,199	7,876	8,169	8,198	1·03
231	8,117	7,794	8,115	8,129	0·90
232	7,508	7,215	7,418	7,528	2·73
233	7,720	7,396	7,645	7,745	2·69
234	8,217	7,926	8,195	8,242	1·14
235	8,338	8,059	8,257	8,285	0·54
236	8,026	7,701	8,077	8,112	1·22
237	7,335	6,925	7,352	7,405	1·15
238	8,369	8,118	8,380	8,410	0·49
239	7,848	7,552	7,951	8,001	0·96
240	8,260	7,947	8,312	8,338	1·36
241	8,150	7,875	8,062	8,109	0·60
242	8,064	7,730	8,121	8,174	1·34
243	8,388	8,090	8,367	8,422	0·99
244	8,302	8,034	8,327	8,363	0·56
245	8,332	8,072	8,368	8,403	0·61
246	8,062	7,731	8,106	8,159	1·20
247	8,258	7,878	8,308	8,345	0·41
248	8,162	7,958	8,079	8,131	0·60
249	8,233	7,968	8,304	8,338	0·61
250	8,398	8,135	8,470	8,502	0·50
251	8,209	7,954	8,198	8,231	0·59
252	8,202	7,956	8,147	8,195	0·82
253	8,253	8,018	8,193	8,224	0·55
254	8,324	8,072	8,346	8,373	0·71
255	8,111	7,847	8,121	8,157	0·90
256	8,043	7,749	8,086	8,127	1·20
257	8,395	8,145	8,360	8,393	0·62
258	8,492	8,232	8,487	8,512	0·67
259	8,413	8,160	8,402	8,430	0·50
260	8,484	8,232	8,468	8,492	0·63
261	8,415	8,165	8,382	8,407	0·69
262	8,423	8,177	8,364	8,394	0·67
263	8,238	7,992	8,247	8,280	0·74
264	8,197	7,942	8,169	8,218	0·70

* Calories per gram.

CHAPTER IV.

Accuracy of Coal Analyses.

By W. Pollard.

Although practically every author on the subject of coals and coal-analysis has discussed, or at any rate alluded to the question of errors in coal-analysis, it will probably be of assistance if a few examples of possible errors are given before examining the table of analyses. These examples may be thought to be exaggerated, but probably all, and possibly some others not mentioned, will be met with sooner or later whenever a large amount of coal-analysis is done.

1.—Proximate Analysis.

In the proximate analysis of a coal it is important to work as much as possible under constant conditions, and so long as this is done duplicate estimations agree fairly well. If, however, the strength of flame, time of heating, size of crucible, &c., be altered, the results will almost invariably differ, and, unless these details are looked after, will be unreliable. Muck* points out that the addition of powdered quartz to a coal increases the coke, and consequently lowers the volatile matter, so that if two coals are being dealt with whose composition is identical as regards combustible constituents, but which differ in the amount of ash, the proximate analysis will be to some extent misleading.

From some experiments carried out in this laboratory it was found that an increase of water gave an increase in the volatile matter. The following figures illustrate this point. In the first column is the analysis of the original coal, in the second the coal plus an addition of 5 per cent. water, in the third with an addition of 12 per cent. water. The results are calculated on the pure coal (*i.e.*, less moisture and ash):—

Volatile matter	37·02	...	37·86	...	38·44
Fixed carbonaceous residue	62·98	...	62·14	...	61·56

* "Chemie d. Steinkohlen," *Bonn*, 1876, p. 16.

The presence in the coal of carbonates also affects the results. In a coal which contained 12 per cent. carbonic acid (present in the coal as carbonate of lime and magnesia), analysed in the Geological Survey Laboratory, the amount of carbonic acid left in the coke after the estimation of volatile matter was only ·9 per cent., hence 11·1 per cent. had gone off as volatile matter. Further, it is not possible to say to what extent the reaction $CO_2 + C = 2CO$ goes on, but this must have a considerable effect on the result.

Pyrites in the coal must also have some effect, but it is not easy to judge to what extent. It will be readily seen from the above remarks that the proximate analysis is not sufficiently reliable as a basis for purposes of classification.

2.—Ultimate Analysis.

The report of Sub-Committee X of the International Committee on Analyses of the Eighth International Congress of Applied Chemistry (1912) requires careful consideration, as errors in the estimation of moisture naturally affect practically all constituents, though especially the hydrogen and consequently the C/H ratio. The following is an outline of the work done by the Sub-Committee.

Samples of six different coals were submitted to the members of the Sub-Committee who were asked to estimate the moisture by various methods, and to submit their results with any recommendations they thought advisable.

The coal-samples were packed ready ground in tins so that each worker should have as far as is possible a true sample. The coals consisted of—

1. A Welsh anthracite.
2. "Ten Yard" or "Thick Coal" of South Staffordshire (rather like a lignite).
3. "Kilburn" Seam of Leicestershire. A coking and household coal.
4. A South American coal. This coal rapidly weathers and contains 37 per cent. of ash. It is of exceptional character and unlike any coal known to us in South Wales. Its consideration might be omitted.
5. A bituminous coal from Leicestershire.
6. A coal from the south-east of Scotland, bituminous, but less so than No. 5.

The following table gives the main results:—

Method 1.—One gramme of Coal heated to 105°–107° C. for one hour.

	Coal No. 1.	Coal No. 2.	Coal No. 3.	Coal No. 4.	Coal No. 5.	Coal No. 6.	Number of Observers.
Maximum	3·24	10·25	8·00	6·42	7·63	8·16	15
Minimum	2·72	9·48	6·52	5·10	6·22	6·92	
Average	2·96	9·84	7·33	5·84	7·20	7·48	
Greatest Difference	·52	·77	1·48	1·32	1·41	1·24	

Method 2.—As 1, but for two hours.

	Coal No. 1.	Coal No. 2.	Coal No. 3.	Coal No. 4.	Coal No. 5.	Coal No. 6.	Number of Observers.
Maximum	3·18	10·27	7·62	6·24	7·36	7·72	12
Minimum	2·54	8·76	5·50	5·08	6·16	6·54	
Average	2·87	9·64	7·08	5·75	6·98	7·20	
Greatest Difference	·64	1·51	2·12	1·16	1·20	1·18	

No. 3.—By method ordinarily employed by each member of Sub-Committee.

	Coal No. 1.	Coal No. 2.	Coal No. 3.	Coal No. 4.	Coal No. 5.	Coal No. 6.	Number of Observers.
Maximum	3·16	10·16	7·79	6·19	7·64	7·95	16
Minimum	2·75	9·30	6·68	5·27	6·92	7·07	
Average	2·99	9·76	7·33	5·71	7·23	7·47	
Greatest Difference	·41	·86	1·11	·92	·72	·88	

No. 4.—By drying in a Vacuum.

	Coal No. 1.	Coal No. 2.	Coal No. 3.	Coal No. 4.	Coal No. 5.	Coal No. 6.	Number of Observers.
Maximum	3·70	10·39	7·98	6·22	7·79	8·41	15
Minimum	2·41	9·01	5·93	3·84	5·98	6·87	
Average	2·95	9·97	7·40	5·35	7·27	7·60	
Maximum Difference ...	1·29	1·38	2·05	2·38	1·81	1·54	

No. 5.—By drying in a current of "inert" gas and also weighing the water given of (— loss, + gain of absorption tube).

	Coal No. 1.		Coal No. 2.		Coal No. 3.		Coal No. 4.		Coal No. 5.		Coal No. 6.		Number of Observers.
	—	+	—	+	—	+	—	+	—	+	—	+	
Maximum	2·96	3·15	10·61	10·62	8·03	8·18	6·51	6·62	7·85	7·98	8·12	7·94	5
Minimum	2·52	2·62	9·46	10·20	7·10	7·83	5·58	6·36	6·65	7·87	7·50	7·72	
Average	2·84	2·91	10·12	10·40	7·57	7·97	6·04	6·46	7·29	7·92	7·69	7·85	
A	·44	·53	1·15	·42	·93	·35	·93	·26	1·20	·11	·62	·22	
B	·63		1·16		1·08		1·04		1·33		·62		
C	·07		·28		·40		·42		·63		·16		

As No. 5, but in air.

	Coal No. 1. —	Coal No. 1. +	Coal No. 2. —	Coal No. 2. +	Coal No. 3. —	Coal No. 3. +	Coal No. 4. —	Coal No. 4. +	Coal No. 5. —	Coal No. 5. +	Coal No. 6. —	Coal No. 6. +	Number of Observers.
	3·15	3·25	10·31	10·68	7·78	8·18	6·09	6·34	7·54	8·01	7·84	8·28	2
	3·19	3·23	10·22	10·38	7·52	8·29	6·42	6·56	7·47	8·37	7·92	8·25	
Maximum Difference	·04	·02	·09	·30	·26	·11	·33	·22	·07	·36	·08	·03	
Maximum Difference + or — ...	·10		·46		·77		·47		·90		·44		

A Maximum difference. B Maximum difference from + or — C Difference of average + or —

In looking at the differences in the first four methods it will be noticed that No. 3 method shows the lowest with the exception of coal No. 2 in method 1. This seems to indicate that practice in carrying out a determination has something to do with obtaining concordant results.

One must not lose sight of the possibility that, in spite of the care taken to supply homogeneous samples, some may have contained less moisture than others when the tests were made. It must be remembered also that some coals weather more easily than others and may absorb or lose more moisture on that account. In the original report indications of the above points will be found on pp. 101, 115 and 118; on p. 115 especially some figures in support of this possibility are given. In the case there mentioned the moisture was estimated on receipt of the samples and again three weeks later. In each case the amount had diminished, in some nearly ·5 per cent. Mr. Johnston, who had worked at Germiston, Transvaal, more than 4,000 feet above sea-level, ascribed "these low figures in the second set to the fact that on opening the tins for weighing purposes a certain amount of moisture was lost by the samples on account of the lower barometric pressure here and of the dry atmosphere as compared with your climate when the samples were crushed and sampled."

Here, therefore, is found a probable explanation of a part at least of the great differences found in some cases. The greatest in any coal is 2·38 per cent. (No. 4, method 4), and this may be taken as an extreme. Probably a fairer estimate would be obtained by taking the greatest difference from the average of each method. These are:—

	Coal No. 1.	Coal No. 2.	Coal No. 3.	Coal No. 4.	Coal No. 5.	Coal No. 6.
Method 1	2·96	9·84	7·33	5·84	7·20	7·48
" 2	2·87	9·64	7·08	5·75	6·98	7·20
" 3	2·99	9·76	7·33	5·71	7·23	7·47
" 4	2·95	9·97	7·40	5·35	7·27	7·60
" 5 Loss	2·84	10·12	7·57	6·04	7·29	7·69
Gain	2·91	10·40	7·97	6·46	7·92	7·85
" 5A Loss	3·17	10·26	7·65	6·25	7·50	7·88
Gain	3·24	10·53	8·23	6·45	8·19	8·26
Maximum difference 1-4...	·12	·33	·32	·49	·29	·40
Maximum difference all above methods	·37	·89	1·15	1·11	1·21	1·06

From the above we may assume that the average error, or rather difference between methods 1 and 4, does not exceed ·5 per cent., whilst if direct weighing of the water is taken the error may be up to 1·2 per cent. Attention must be drawn to the fact that in all water-estimations in coals analysed by or specially for the Geological Survey for the purposes of this Memoir the first method has been used, and that the results will therefore be comparable one with another. Even if there is an under- or over-estimate of the moisture absolutely present in the coal, this error will probably be fairly constant, and will

therefore not appreciably affect the relative C/H value of the different coals.

The Report, where the method of drying at 105° C. is discussed (p. 89), shows also that the differences in the individual results where the coals were weighed in closed vessels were:—

·29 ·63 ·30 1·04 ·40 ·53

If coal No. 4 is omitted for reasons already stated, the greatest difference is ·63 per cent., and this in all probability represents the maximum error likely to occur. That the loss may not represent the absolute amount of moisture is admitted, for in almost every case where the water given off was weighed it was found to be greater than the loss in weight of the coal (*see* p. 105), but results will be comparable.

In order to illustrate the effect upon the C/H ratio which errors in the estimation of moisture may produce, we select examples of two of the classes of coal met with in South Wales. Nos. 13 and 20 represent anthracitic and bituminous coals respectively, and we assume the errors in moisture to be (1) maximum, 2·4 per cent., (2) 1·2 per cent., (3) ·5 per cent.

For each unit of moisture 1/9 will be rendered as H. Hence the hydrogen-equivalents will be (1) ·27, (2) ·13, (3) ·06 approximately. This on the coals selected gives:—

	C.	H.	C/H.	
Coal No. 13.—				
Original	94·43	3·33	28·36	Max. difference in C/H ratio, 2·13.
Plus ·06 % H	94·43	3·39	27·85	
·13	94·43	3·46	27·29	
·27	94·43	3·60	26·23	
Coal No. 20.—				
Original...	88·65	6·29	14·09	Max. difference in C/H ratio, ·59.
Plus ·06 % H	88·65	6·35	13·95	
·13	88·65	6·42	13·80	
·27	88·65	6·56	13·50	

It will be seen that these differences, though apparently large, do not seriously affect the position of a coal in classification. As an extreme case an anthracite might drop to a semi-anthracite in the classification of the U.S.G.S. as given on p. 60. It will be noted also that the figures taken are extremes. Moreover, large variations are less frequent in the anthracitic classes of coal, and a difference of even 2·38 per cent. in moisture in the bituminous class only makes roughly ·6 in the C/H ratio.

Ash.—By ash is meant all non-combustible matter in the coal. The value obtained depends to some extent on how the ash is estimated. For instance, the value for the ash left in the combustion-tube is almost invariably higher than that obtained by ashing in the muffle. The reason appears to be that in the combustion-tube, where the coal is burned in oxygen, more of the sulphur is converted to sulphuric anhydride, which combines with any lime in the ash, whilst in the muffle the atmosphere is less highly oxidising, so that more of the sulphur goes off as a lower oxide, instead of combining with the lime in the ash. The following case supports this view:—

A coal gave 4·80 per cent. ash in the muffle and 5·26 in the combustion-tube. The sulphur in the lower ash was ·11 per

cent., in the higher ·30 per cent. If the difference of the two sulphurs (·19 per cent.) be calculated as SO_3, ·47 is obtained, whilst the difference in the two ashes is ·46 per cent.

In every case where the ash has been estimated in both ways the muffle has given the lower result both in ash and sulphur-in-ash. Should minerals containing ferrous compounds be contained in the coal, these, during combustion of the coal in oxygen, will become (to a great extent, at any rate) ferric. Hence the ash as found by analysis will be greater than the original ash in the coal, and the oxygen which is obtained by difference will consequently be too low. To take a possible case: the composition of a coal as found by analysis is:—

C	83·6
H	4·0
O	1·2
N	1·4
Ash	8·6
Moisture	1·2
	100·00

Supposing that the ash as here found contains 2 per cent. of Fe_2O_3 which was present in the original coal as FeO, the real ash would be represented by 8·6 − 2·0 + FeO, equivalent to 2·0 Fe_2O_3, which is 1·8. Hence true ash is 8·4 instead of 8·6, and the oxygen 1·4 instead of 1·2. Recalculating both to the pure coal (*i.e.*, coal free of water, ash and combustible sulphur), the following figures are obtained:—

	Uncorrected.	Corrected.	Difference.
C	92·69	92·48	·21
H	4·43	4·43	—
O	1·33	1·54	·20
N	1·55	1·55	—
C/H	21·40	21·36	·04

(The 2 per cent. of Fe_2O_3 here supposed to exist represents 23 per cent. of the ash. Cases are given by Percy where 44 per cent. of the ash of a Welsh coal was composed of Fe_2O_3, but it is not possible to say if any of it was present as FeO in the original coal. This error is hardly ever likely to be of serious importance except in coals abnormally rich in ash.)

Pyrites.—We may take next the effect of pyrites. When coal containing this mineral is burned in oxygen, the pyrites is converted into ferric oxide and oxides of sulphur; the latter are absorbed by the lead chromate in the combustion-tube, while the former remains in the boat and is weighed with the rest of the ash. The pyrites cannot be regarded as part of the organic combustible constituents of the coal any more than the rest of the ash and the moisture, but for every 240 parts of weight of pyrites present in the coal 160 parts of ferric oxide and 128 of sulphur are being counted. The effect of this is that the

estimate for oxygen, which is obtained by difference, is too low. The following example, in which all the combustible sulphur has been assumed to be present as pyrites, illustrates this error:—

Composition as obtained by analysis.		All S taken as $Fe\,S_2$, and the equivalent $Fe_2\,O_3$ deducted from the ash.		
C	83·65		83·65	
H	4·02		4·02	
O	1·17		2·01	
N	1·45		1·45	
S. combustible ...	2·23	FeS_2	4·17	true ash of original coal.
Ash	6·31	Ash less $Fe_2\,O_3$ equiv. to 4·17 FeS_2	3·53	
Moisture	1·17		1·17	

Recalculated on to 'Pure Coal.'			Difference.
C	92·65	91·80	·85
H	4·45	4·41	·04
O	1·30	2·20	·90
N	1·60	1·59	·01
C/H ratio	20·8	20·8	—

*Carbonates.**—Carbonates in the coal are more or less decomposed during analysis and give off carbonic acid gas. This is absorbed by the potash-bulbs and is weighed with the carbonic acid formed by the combustion of the carbon of the coal, the result being that the carbon is too high, the true ash too low, and the oxygen too high. When the results of the analysis are calculated on the pure coal all constituents will be affected. In the following example the 6·2 per cent. of ash is assumed to contain 2 per cent. of calcium oxide which was originally present as calcium carbonate. Hence ash less CaO is 4·2 per cent., and CO_2 equivalent to the CaO, 1·57. This makes the ash, plus non-organic constituents, 7·77 instead of 6·2. As in combusting the coal all the CO_2 is assumed to be driven off, the percentage of carbon will be too high by C/CO_2, or 3/11 of 1·57, or ·43 per cent., and the ash too low by 1·57 per cent., the difference falling on the oxygen. The effect would thus be:—

	Uncorrected.	Corrected.	Difference.
C	85·23	84·80	·43
H	3·64	3·64	—
O	1·83	·69	1·14
N	1·29	1·29	—
S combustible...	1·81	1·81	—
Ash	6·20	7·77	1·57

* Cf. Alix-and Bay. *Compt Rendu*, vol. cxxxix. (1904), p. 215.

or calculated on to pure coal:—

	Uncorrected.	Corrected.	Difference.
C	92·65	93·79	1·14
H	3·96	4·03	·07
O	1·98	·76	1·22
N	1·41	1·42	·01
C/H ratio ...	23·4	23·3	·1

(No notice has been taken of the sulphur in this example, which is only to illustrate the error caused by carbonates.)

In practice it has been found that the amount of CO_2 left in the ash varies considerably with each estimation, so that to make the necessary correction the CO_2 has to be estimated specially in the ash left after each combustion. When this is done duplicates agree well.

The next analysis is quoted as showing how the type of coal may be mistaken unless correction is made. It is an extreme case, but one that has actually occurred in the course of coal-analysis in this laboratory. The coal in question was one that had been baked by a whin-sill. It contained 25·2 per cent. of ash and 12·2 per cent. of CO_2, so the true ash (the incombustible portion) was 37·4 per cent. The figures give the composition of the pure coal (*i.e.*, free from ash, moisture and combustible sulphur), the first column uncorrected, the second the true composition:—

	Uncorrected.	Corrected.	Difference.
C	88·69	93·13	4·44
H	2·80	3·01	·21
O	7·18	2·44	4·74
N	1·33	1·42	·09
C/H ratio ...	31·7	30·9	·8

Where both carbonates and pyrites are present there will naturally be complications, as the oxides of sulphur will combine with the lime or magnesia of the carbonates, thus lowering the combustible sulphur and increasing the sulphur-in-ash. It is not possible, however, to correct for this.

Hydrous Minerals.—A possible source of error affecting the hydrogen would be the presence in the ash of minerals containing water of constitution not driven off at 105° C.* As an example (and probably an extreme one), were 5 per cent. of kaolin (which contains about 14 per cent. of water) to be contained in a coal, and were all the water (·7 per cent. on the sample of coal plus ash) driven off and absorbed in the U-tube, the hydrogen would be too high by 1/9th of ·7 per cent. or ·08 per cent. This would give a difference of ·3 to ·5 on the C/H ratio, according to the class of coal. It is hardly likely, however, that a coal would be met with containing so great an amount of hydrous minerals.

* Cf. C. von John. *Verh. d. K.K. Geol. Reichsanstalt*, 1904, p. 104.

Deterioration on Keeping.—The fact that many coals deteriorate, and that some are liable to spontaneous combustion when stored, has been the subject of a large number of papers. Percy* goes into this question, quoting the researches of Geinitz, Fleck and Hartig,† E. Richters‡ and others, pointing out the fact that it is something besides the pyrites which produces the change. More recent observations even suggest a doubt whether pyrites, except when present in large amount, produces spontaneous combustion. From the discussion on a paper entitled 'On the Prevention of Spontaneous Combustion of Coal at Sea,'§ opinions appear to be divided, though it seems that whilst pyrites does not fire when pure, it is liable to heat and take fire if mixed with organic matter, as in coal.

Prof. Fischer‖ has published a paper going fully into the question and giving a *résumé* of the older investigations. He tried the effect of bromine on coals and found that both addition- and substitution-products were formed, the addition-products showing the presence of unsaturated compounds. When moist air was passed over powdered coal carbonic acid and water were formed, the coal increasing in weight. If the coal was then heated to 120° or 150° C., it lost weight through more or less of the carbonic acid and water being driven off. It was found that powdered coal absorbed oxygen more rapidly than lumps, as was to be expected. After a coal had been subjected to this slow oxidation in moist air, it was found to absorb far less bromine than the same sample before oxidation, an additional proof that change in composition had occurred. A test, based on the bromine reaction, is suggested for finding out whether a coal is liable to spontaneous combustion or not. If this test is really satisfactory it should be of considerable value to those who store or transport large quantities of coal.

The following are, briefly, the conclusions drawn from this paper. Coals contain varying quantities of unsaturated compounds which rapidly absorb oxygen, thereby gaining in weight but deteriorating in coking properties and calorific value. Another series of compounds also occurs which take up oxygen, but give off carbonic acid and water in the process. The latter process, which is usually slow, produces a loss in both the weight and value of the coal. A coal on storing therefore may gain, lose, or remain constant in weight, according to the quantities and relative proportions of the two classes of compounds present, but will almost invariably deteriorate in value. When coals are stored in a cool dry place the alteration is, in most cases, inconsiderable. Moisture certainly assists in the oxidation of the coal. The effect of pyrites on spontaneous combustion is undoubtedly over-estimated. The value of ventilating stored coals is doubtful, as although ventilation will help in cooling, it will supply the oxygen necessary to produce combustion.

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* 'Metallurgy,' Ed. 1875, pp. 289, 300.

† "Die Steinkohlen Deutsohlands u. a. Laender," 1865, vol. ii, p. 221.

‡ *Dingler, Polyt. J.*, vol. cxcv., 1870, p. 315 and 449, vol. cxcvi, p. 317. Also *Wagner's Jahresber*, 1870, vol. xvi, pp. 758-778.

§ T. W. Bunning. *Trans. N. of England Inst. M.E.*, vol. xxv, 1876, p. 107.

‖ *Z. Angew Ch.*, 1899, pp. 564, 764, 787.

In connection with the absorption of bromine by coals, it should be mentioned that F. Hart has recently published the results of an investigation on the absorption of iodine, and on the action of sulphuric acid and alcoholic potash or coals. Alcoholic potash extracts a dark substance from caking coals which readily cokes, whilst the coal after this treatment loses its coking properties.*

Since the first edition of this Memoir was published, the sixth volume of "An Investigation of the Coals of Canada" (1912) has appeared. In it an important paper on the Spontaneous Combustion of Coal, by E. Stansfield, is reproduced from the publications of the Canadian Mining Institution (1910). The paper furnishes references to the literature and contains important suggestions on this subject.

In order to see to what extent the composition of coals would be affected by keeping, four of the samples stored in this museum were re-sampled and analysed afresh, with the following results. In each case the first column gives the composition of the fresh coal, sampled and analysed soon after it was sent from the pit, the second after it had been stored in a tin-box, the length of time stored being in each case stated. The coals were stored in the basement of the Jermyn Street Museum, where they were not subjected to great changes of temperature.

Nine-Foot Vein. Anthracite. Stored Four Years.

	Analysis in 1903.	Analysis in 1907.
C	93·15	93·13
H	3·59	3·52
O	1·89	1·99
N	1·37	1·36
Sp. Gr. (pure coal)‡	1·396	1·403
C/H ratio	25·9	26·5

In this case the change may be taken as *nil,* all variation being within experimental error.

Nine-Foot Vein. Steam Coal. Stored Four Years.

	Analysis in 1903.	Analysis in 1907.
C	91·58	91·34
H	4·51	4·42
O	2·36	2·67
N	1·55	1·57
Sp. Gr. (pure coal)‡	1·316	1·329
C/H ratio	20·3	20·7

* *Chem. Ztg.,* vol. xxx, p. 1,204 ; and vol. xxxi, p. 640.

‡ See footnote on page 44.

The variation here is almost within experimental error, but the change, slight as it is, is in the direction to be expected.

Mynyddislwyn Vein. A Bituminous Coal. Stored Four Years.

	Analysis in 1903.	Analysis in 1907.
C	86·94	85·55
H	5·64	5·43
O	5·84	7·27
N	1·58	1·75
Sp. Gr. (pure coal)‡	1·290	1·316
C/H ratio	15·4	15·8

Top Coal of Rock Vein. A Bituminous Coal. Stored Five Years Seven Months.

	Analysis in 1901.	Analysis in 1907.	Analysis in 1907.
C	88·30	87·11	87·34
H	5·45	5·40	5·34
O	4·83	5·94	5·78
N	1·42	1·55	1·54
Sp. Gr. (pure coal)‡	1·272	—	1·299
C/H ratio	16·2	16·1	16·3

First column, original analysis; second, original fine-ground sample, stored in a bottle all the time; third, original sample stored in a tin box and resample after the $5\frac{1}{2}$ years.

The difference between the two stored samples may well be only due to experimental error, but with both the bituminous coals the difference between the fresh and the stored samples is marked.

It is noticeable that the anthracite has altered least (if at all), the steam-coal only slightly, whilst the bituminous coals have changed considerably. In each case the change is in the same direction, and though, as already stated, no great accuracy can be claimed for the specific gravity of the pure coal, owing to the possible sources of error discussed on pp. 12 and 38 (to say nothing of the pyrites having partially decomposed in the stored specimen), yet the general indication is that the greater the alteration in the composition the greater the alteration in the specific gravity. The differences are:—

Loss of carbon	(·02)	·24	1·39	·96
Gain in specific gravity...	(·007)	·013	·026	·020

‡ The specific gravity of the "pure coal" in the above cases has been obtained by correcting for the specific gravity of the ash as found in each case. (See under Specific Gravity, page 12.)

The change, at any rate in the bituminous coals, is greater than can be reasonably put down to experimental error.

The alteration is similar to that observed by Richters, Fleck, Bischoff, and others, and quoted by Percy (*loc. cit.*, pp. 289–298), with the possible exception of the specific gravity. In the examples given by Fleck (*Die Steinkohlen Deutschlands u. andere Laender*, vol. ii., p. 219) the variation of specific gravity is only ·011 in one case and less than ·01 in the others; in the cases quoted by Richters* some showed an increase and some a decrease in specific gravity. Unluckily the specific gravity of the ash is not given, so it is not possible to calculate the results for the pure coal. The great difficulty in commenting on results of this kind is that it is impossible to say whether any constituent remains the same, with possibly the exception of ash, and, as has already been shown, the estimation of ash is at the best of times unsatisfactory. Were the alteration of coals by storage to be at any time reinvestigated, it would be well to take a pound or two of the finely-ground sample and thoroughly mix with it, say, 1 per cent. of some inert and easily determinable substance (*e.g.*, gold-dust), then divide up into lots to be periodically examined. There would then be one constant from which to calculate the changes that had occurred.

The following is a summary of the approximate errors so far considered:—

	C per cent.	H per cent.	O per cent.	N per cent.	C/H ratio.
Ferrous minerals in ash ...	·2	—	·2	—	·1
Pyrites	·85	·05	·90	·01	—
Carbonates	1·14	·07	1·22	·01	·1
Ditto in extreme case ...	4·4	·2	4·7	·1	·8
Hydrous minerals	—	·1	—	—	? ·4
Maximum observed alteration in four Welsh coals after storage.	1·39	·21	1·43	·17	·51
Error in moisture affecting C/H ratio (in extreme cases).	·5 to about 2·2				

No great accuracy is claimed for these figures, they are only intended to show in what direction, and approximately to what extent, the composition of a coal may be affected.

* *Dingler, Polyt, J.*, vol. cxcvi (1870) p. 321.

CHAPTER V.

Comparison of Different Bands of the Same Seam and Comparison of Different Samples from the Same Seam in the Same Locality.

By W. Pollard.

After considering the possible analytical errors the following questions arise:—What variation is met with in the composition of—

1. Coal in different parts of the same seam (*i.e.*, top, middle, and bottom coals).
2. Different samples from the same seam and pit.

Nine cases are available under heading 1. These are given in the following table:—

Analysis No.	C %	H %	O & N %	C/H ratio.
61. (Nos. 118, 119, 120 of Percy)				
Top Coal	91·63	4·98	3·39	18·4
Middle Coal	92·45	4·89	2·66	18·9
Bottom Coal	91·30	4·72	3·98	19·3
152. Top Coal	92·65	4·45	2·90	20·8
153. Middle Coal	90·58	4·33	5·09	20·9
154. Bottom Coal	91·49	4·45	4·06	20·6
155. Top Coal	90·91	4·79	4·30	19·0
156. Middle Coal	88·64	4·72	6·64	18·8
157. Bottom Coal	89·98	4·82	5·20	18·7
158. Top Coal	92·40	4·38	3·22	21·1
159. Middle Coal	91·36	4·32	4·32	21·2
160. Bottom Coal	90·48	4·34	5·18	20·9
183. Top Coal	92·55	4·88	2·57	18·9
184. Middle Coal	91·26	4·56	4·18	20·0
185. Bottom Coal	92·70	4·44	2·86	20·9
186. Top Coal	91·54	4·62	3·84	19·8
187. Bottom Coal	92·52	4·78	2·70	19·4
300. Top Coal	93·99	3·62	2·39	25·96
301. Middle Coal	94·88	3·64	1·48	26·07
302. Bottom Coal	93·54	3·67	2·79	25·49
Mean	94·14	3·64	2·22	25·86
Cf. No. 131	94·08	3·79	2·13	24·85

Analysis No.	C %	H %	O & N %	C/H ratio.
314. Top 10 inches	91·99	4·32	3·69	21·29
315. Middle, 3 ft. 9 ins.	92·07	4·65	3·28	19·80
316. Lower 1 ft. 6 ins	92·03	4·40	3·57	20·91
317. Bottom 2 ft.	92·38	4·35	3·27	20·93
278. Top	85·95	5·46	8·59	15·74
279. Middle	85·49	5·63	8·88	15·18
280. Bottom	86·62	5·60	7·78	15·40
Mean	86·02	5·56	8·42	15·47
Cf. No. 274	87·76	5·27	6·97	16·65

Under the second heading twenty-six cases occur, in some of which there are more than two analyses from the same locality available. These are given in the following pages.

Vein.	C %	H %	O & N %	C/H ratio.	Fuel-ratio.
Black [or Ras-las]	88·66	4·89	6·45	18·1	2·25
" "	86·85	4·77	8·38	18·2	—
Difference	1·81	·12	1·93	·1	—
Black [or Ras-las]	88·24	5·24	6·52	16·8	1·91
" "	90·74	4·84	4·42	18·7	—
" "	90·45	5·28	4·27	17·1	—
Maximum difference ...	2·50*	·44	2·25*	1·9	—
Black [or Ras-las]	87·49	5·33	7·18	16·4	1·74
" "	89·27	5·60	5·13	15·9	2·87
Difference	1·78	·27	2·05	·5	1·13
Big [probably above the Ras-las]	93·77	3·74	2·49	25·1	14·46
" " ...	93·63	3·70	2·67	25·3	—
" " ...	93·99	3·76	2·25	25·0	—
" " ...	93·87	3·76	2·37	25·0	13·87
Maximum difference ...	·36	·06	·42	·3	·59
Big [or Ras-las]	93·56	3·57	2·87	26·2	15·95
" "	93·21	3·57	3·22	26·1	10·76
" "	92·46	3·20	4·34	28·9	—
Maximum difference ...	1·10	·37	1·47	2·8	5·19

* Greatest difference observed in this Table.

Vein.	C %	H %	O & N %	C/H ratio.	Fuel-ratio.
Four Foot [of Clyne Valley]..	88·80	5·36	5·84	16·6	2·31
" " ...	88·51	5·02	6·47	17·6	2·56
Difference	·29	·34	·63	1·0	·25
Big [or Ras-las]	93·87	3·59	2·54	26·2	22·8
" "	93·97	3·50	2·53	26·9	16·2
" "	94·49	3·67	1·84	25·8	—
Maximum difference ...	·62	·17	·70	1·1	6·6
Big [or Ras-las]	93·91	3·70	2·39	25·4	15·4
" "	93·16	3·52	3·32	26·4	—
Difference	·75	·18	·93	1·0	—
Little [or Brass]	94·19	3·58	2·23	26·3	18·5
" "	94·36	3·63	2·01	26·0	—
Difference	·17	·05	·22	·3	—
Peacock [or Brass]	93·39	3·66	2·95	25·5	18·0
" "	93·80	3·16	3·04	29·6	—
Difference	·41	·50	·09	4·1*	—
Rock Vawr [No. 2 Rhondda]	85·23	4·80	9·97	17·8	1·46
" "	84·78	5·57	9·65	15·2	1·31
Difference	·45	·77*	·32	2·6	·15
No. 2 Rhondda	91·78	5·13	3·19	17·9	4·47
	91·66	4·85	3·49	18·9	4·12
	91·66	4·43	3·91	20·7	5·05
Difference	·12	·70	·72	2·8	·93
Three Quarter [of Monmouthshire] ...	87·81	5·09	7·10	17·3	2·09
" " ...	89·64	4·37	5·99	20·5	—
Difference	1·83	·72	1·11	3·2	—
Graigola	92·73	4·64	2·63	20·0	—
"	91·70	4·80	3·50	19·1	5·37
Difference	1·03	·16	·87	·9	—

* Greatest difference observed in this Table.

Vein.	C %	H %	O & N %	C/H ratio.	Fuel-ratio.
Tregloin	93·79	3·67	2·54	25·6	17·8
,, ...	93·78	3·59	2·63	26·1	17·1
Difference	·01	·08	·09	·5	·7
Red [of the Neath Valley] ...	93·26	3·89	2·85	24·0	12·6
,, ,, ...	92·74	3·96	3·30	23·4	12·9
,, ,, ...	92·48	4·03	3·49	23·0	15·6
Maximum difference ...	·78	·14	·64	1·0	3·0
Red [of the Neath Valley] ...	93·56	3·48	2·96	26·9	—
,, ,, ...	93·42	3·39	3·19	27·5	10·1
Difference	·14	·09	·23	·6	—
Red [of the Neath Valley] ...	93·32	3·84	2·84	24·3	14·6
,, ,, ...	94·08	3·79	2·13	24·9	14·4
Difference	·76	·05	·71	·6	·2
Red [of the Neath Valley] ...	93·02	4·27	2·71	21·8	12·7
,, ,, ...	92·58	3·91	3·50	23·7	12·0
Difference	·44	·36	·79	1·9	·7
Big	93·72	3·68	2·60	25·5	15·97
,, ...	93·90	3·57	2·53	26·3	14·75
Difference	·18	·11	·07	·8	1·22
Stanllyd	94·06	3·47	2·47	27·1	16·52
,, ...	94·09	3·48	2·43	27·0	18·27
Difference	·03	·01	·04	·1	1·75
Red	93·42	4·02	2·56	23·2	14·38
,, ...	93·22	3·85	2·92	24·2	10·43
Difference	·20	·17	·36	1·0	3·95
Nine foot	93·83	3·81	2·36	24·6	12·83
,, ...	93·67	3·81	2·52	24·6	12·79
Difference	·16	—	·16	—	·04

Vein.	C %	H %	O & N %	C/H ratio.	Fuel-ratio.
Nine Foot	91·40	4·78	3·82	19·1	4·69
„	91·43	4·61	3·96	19·8	4·15
Difference	·03	·17	·14	·7	·54
Nine foot	91·73	4·29	3·98	21·4	5·05
„	92·11	4·19	3·70	22·0	6·24
Difference	·38	·10	·28	·6	1·19
Peacock	93·70	3·90	2·40	24·0	14·76
Brass	93·88	3·73	2·39	25·2	14·50
Difference	·18	·17	·01	1·2	·26

The greatest differences observed in the two cases are therefore:—

(1) Different parts of the same vein:—

	C %	H %	O & N %	C/H ratio
Maximum difference	2·27	·44	2·34	2·0
Mean of max. differences ...	1·4	·19	1·49	·8

(2) In same vein and pit but different samples and sometimes different analysts:—

	C %	H %	O & N %	C/H ratio
Maximum difference	2·50	·77	2·25	4·1
Mean of max. differences ...	·64	·24	·67	1·2

From the above data it will be seen that it is impossible to lay down on a map the composition of the coals with minute accuracy, and that the exact limits of anthracite, steam-, and house-coals is still indefiuite, from a chemical point of view. It is quite possible that some of the early analyses may be inaccurate, for when charcoal-furnaces only were available for making combustions, the labour and difficulties must have been great. It should also be borne in mind that, in many cases, no details as to the collection of the samples are available, so that it is possible that the analyses in some cases represent a part of the vein only, and not the average composition of the whole thickness.

CHAPTER VI.

Comparison of Different Seams in the Same Locality.

By W. Pollard.

It is frequently the case that the lower the vein, in geological sequence, the more anthracitic it is. This rule, if proved to be universally correct, would be a point in favour of anthracitisation having been due to a cause operating from beneath. Also it should be possible, if the composition of the upper veins were known, to predict what the approximate composition of the lower veins would be. To test these points the following table of analyses of different veins from the same pits has been prepared, giving the approximate distance between veins, composition of the pure coal, C/H ratio, and fuel-ratio.

Vein.	Distance between veins in yards.	C %	H %	O & N %	C/H* ratio.	Fuel-† ratio.
Charcoal ...		84·56	6·57	8·87	12·9	2·10
	174					
Black		87·49	5·33	7·18	16·4	1·74
		89·27	5·60	5·13	15·9	2·87
Four Foot ...		93·69	3·74	2·57	25·1	13·9
	47					
Big		93·16	3·52	3·32	26·4	—
		93·91	3·70	2·39	25·4	15·4
	21					
Peacock... ...		94·02	3·96	2·30	23·7	12·9
Four Foot ...		93·77	4·64	1·59	20·2	7·92
„ Dyffryn ...		92·93	4·91	2·16	18·9	5·16
	54 to 70					
Nine Foot ...		91·89	4·59	3·54	20·0	6·03
Red		87·77	4·97	7·26	17·7	2·22
	17					
Three Quarter ...		86·63	5·13	8·24	16·9	1·95
	20					
Rock		88·30	5·45	6·25	16·2	1·77
		88·61	5·29	6·10	16·8	2·03
Deep Black ...		87·76	5·27	6·97	16·7	2·04
	50					
Old		87·93	5·30	6·77	16·6	2·18
No. 2 Rhondda	75 to 80	92·64	4·74	2·62	19·5	4·77
Graig		92·57	4·72	2·71	19·6	5·12
	151 to 210					
Two Foot Nine...		94·11	4·19	1·70	22·5	8·06
	12 to 22					
Four Foot ...		92·74	3·96	3·30	23·4	8·75

* The relative proportion of carbon to hydrogen. *See* Chap. VII.
† The relative proportion of coke to volatile matter. *See* Chap. VII.

Vein.	Distance between veins in yards.	C %	H %	O & N %	C/H ratio.	Fuel-ratio.
Big or Stanllyd		94·21	3·75	2·04	25·1	16·4
		93·82	3·81	2·37	24·6	16·2
		93·13	2·17	4.70	43·0*	—
	35					
Peacock ...		93·67	3·73	2·60	25·1	16·1
	48					
Middle		94·31	3·64	2·05	25·9	18·1
	17					
Lower		94·09	3·58	2·33	26·3	18·5
Elled		84·42	5·48	10·10	15·4	—
	5 to 11					
Big		87·14	6·49	6·37	13·4	—
	8 to 12					
(Top of) Three Quarter		89·81	5·11	5·08	17·6	2·99
Three Quarter ...		86·25	5·90	7·85	14·6	—
	83 to 99					
Old		90·74	5·23	4·03	17·4	3·40
No. 2 Rhondda		93·58	4·05	2·37	23·1	12·1
	70					
Lower		93·71	3·69	2·60	25·4	12·4
Four Foot ...		88·51	5·02	6·47	17·6	2·56
		88·80	5·36	5·84	16·6	2·30
	12					
Yankee		88·12	5·57	6·31	15·8	2·24
	10					
Yard		87·22	5·49	7·29	15·9	2·20
Upper Four Foot		90·92	4·51	4·57	20·2	—
	64 to 71					
Ras-las		90·87	4·65	4·48	19·5	—
Graig		91·66	4·71	3·63	19·5	4·10
	151 to 210					
Two Foot Nine...		93·35	4·15	2·50	22·5	7·96
	12 to 22					
Four Foot ...		91·86	3·93	4·21	23·4	8·42
	23 to 35					
Six Foot ...		92·73	3·95	3·32	23·5	7·31
Big		93·17	2·12	4·71	43·9*	—
	35					
Peacock ...		93·94	3·77	2·29	24·9	15·4

* See Note on p. 63.

Vein.	Distance between veins in yards.	C %	H %	O & N %	C/H ratio.	Fuel-ratio.
Six Foot ...		93·63	4·01	2·36	23·4	—
	49					
Nine Foot ...		92·65	3·96	3·39	23·4	10·7
Red		93·03	3·51	3·46	26·5	11·9
	332					
Big		93·92	3·55	2·53	26·5	19·0
		94·49	3·67	1·84	25·8	—
	20 to 35					
Brass		93·39	3·66	2·95	25·5	18·0
		93·80	3·16	3·04	29·6	—
Big		87·81	5·12	7·07	17·2	2·03
	5 to 14					
Three Quarter ...		87·20	5·10	7·70	17·1	2·05
	54 to 59					
Meadow ...		87·16	5·42	7·42	16·1	1·95
Yard		90·53	4·98	4·49	18·2	3·32
	39					
Cae David ...		87·99	5·64	6·37	15·6	1·91
		90·78	5·13	4·09	17·7	3·04
	146					
Duffryn ...		89·75	4·92	5·33	18·2	3·29
	20					
Lower Six Foot		91·25	4·84	3·91	18·9	3·96
	38 to 43					
Nine Foot ...		91·37	4·93	3·70	18·5	3·99
Four Foot ...		85·20	5·40	9·40	15·8	2·27
	73					
Nine Foot ...		86·30	5·34	8·35	16·2	2·29
	59					
Cribbwr ...		87·50	5·15	7·35	17·0	2·46
Penyfilia or Five Foot.		91·66	4·87	3·47	18·8	4·32
		88·66	6·03	5·31	14·7	2·84
	141					
Six Foot ...		90·75	4·73	4·52	19·2	3·93
	13					
Three Foot ...		91·46	5·02	3·49	18·2	4·08
Forest		86·38	5·37	8·25	16·1	—
	5 to 8					
No. 3 Rhondda		88·44	5·32	6·24	16·6	2·94
Wernffraith ...		92·45	4·80	2·75	19·3	—
	199 to 256					
Graigola ...		92·73	4·64	2·63	20·0	—
		91·70	4·80	3·50	19·1	5·37

Vein.	Distance between veins in yards.	C %	H %	O & N %	C/H ratio.	Fuel-ratio.
Red		92·48	4·03	3·49	23·0	15·6
	333					
Big		93·96	3·74	2·30	25·1	17·2
Eighteen Foot ...		93·52	3·82	2·62	24·5	13·3
	9 to 16					
Cornish		93·83	3·95	2·22	23·8	13·8
	30 to 35					
Nine Foot ...		93·79	3·86	2·35	24·3	15·0
Tillery		86·28	5·53	8·19	15·6	1·60
	232					
Big		90·58	5·39	4·03	16·8	—
	5					
Three Quarter ...		87·81	5·09	7·10	17·2	2·09
		89·64	4·37	5·99	20·5	—
	30					
Black		88·24	5·24	6·52	16·8	1·91
		90·74	4·84	4·42	18·7	—
Lower Trichwart		94·1	3·6	2·3	26·1	18·6
	about 17					
Lower Pumpquart		93·00	3·68	3·32	25·3	18·3
Drap		92·59	4·54	2·87	20·4	—
	83					
Green		93·98	3·88	2·14	24·2	13·9
	26					
Big		93·83	3·74	2·43	25·1	13·9
		93·77	3·74	2·49	25·1	14·5
Slatog		83·63	5·28	11·09	15·8	1·80
	36 to 38					
Curly		85·93	5·92	8·15	14·5	1·65
	14 to 17					
Bodwr		85·69	5·81	8·50	14·7	1·97
	17 to 18					
Hughes		77·40	4·67	17·93	16·6	·94
Big		95·15	2·11	2·74	45·1*	
	21					
Peacock ...		93·73	3·22	3·05	29·1	
Ward's Fiery ...		94·68	4·23	1·09	22·4	
	220					
Graigola ...		90·14	5·03	4·83	17·9	3·82

* See Note on p. 63

Vein.	Distance between veins in yards.	C %	H %	O & N %	C/H ratio.	Fuel-ratio.
Four Foot ...	120	92·03	4·70	3·27	19·6	5·60
Five Foot ...		92·17	4·63	3·20	20·0	5·87
Four Foot ...	44	91·81	3·99	4·20	23·0	
Big		93·88	3·65	2·47	25·7	
Stanllyd ...		94·06	3·47	2·47	27·1	16·5
,, ...		93·31	3·02	3·67	30·9	—
,, ...	114	94·09	3·48	2·43	27·0	18·3
Trichwart ...	46	94·16	3·45	2·39	27·3	17·3
Lower Pumpquart		94·31	3·35	2·34	28·2	18·6
Red	290	93·99	3·67	2·34	25·6	13·6
Little		94·19	3·58	2·23	26·3	18·5
,, ...		94·36	3·63	2·01	26·0	—
Red	333	93·92	3·70	2·38	25·4	13·7
Big	20	94·29	3·42	2·29	27·6	16·1
Peacock ...	19	94·44	3·42	2·14	27·6	16·4
Tregloin... ...		93·79	3·63	2·58	25·8	17·5
Four Foot ...	260	91·37	4·49	4·14	20·4	5·3
Golden		93·16	4·17	2·67	22·3	7·5
Stanllyd ...	20	93·47	3·62	2·91	25·8	15·0
Peacock ...		93·92	3·57	2·51	26·3	—
Four Foot ...	116	91·54	4·34	4·12	21·1	5·4
Five Foot ...		90·82	4·28	4·90	21·2	4·1
Big	20	93·37	3·43	3·20	27·2	17·5
Brass		93·88	3·73	2·39	25·2	14·5
Peacock ...	65	93·70	3·90	2·40	24·0	14·8
Lower		94·52	3·51	1·97	26·9	15·3

Vein.	Distance between veins in yards.	C %	H %	O & N %	C/H ratio.	Fuel-ratio.
Nine Foot ...		93·83	3·81	2·36	24·6	12·8
,, ...	20	93·67	3·81	2·52	24·6	12·8
Peacock ...		93·90	3·68	2·42	27·6	15·0
No. 3 Rhondda	350	91·86	4·79	3·35	19·2	3·8
Nine Foot ...		91·92	4·15	3·93	22·2	6·3
Six Foot ...	6	91·32	4·28	4·40	21·3	5·6
Red		91·80	4·31	3·89	21·3	5·9
Four Foot ...	24	91·79	4·31	3·90	21·3	5·9
Six Foot ...	31	91·33	4·23	4·44	21·6	5·5
Nine Foot ...		91·64	4·34	4·02	21·1	6·1
Four Foot ...	19	92·00	4·34	3·66	21·2	5·8
Six Foot ...	39	91·65	4·45	3·90	20·6	5·2
Nine Foot ...		91·58	4·51	3·91	20·3	4·6
Six Foot ...	45	90·13	4·44	5·43	20·3	4·9
Nine Foot ...		91·13	4·49	4·38	20·3	5·1
Six Foot ...	45	90·99	4·58	4·43	19·9	4·1
Nine Foot ...		91·03	4·54	4·43	20·0	5·0
Fforest Fach ...	347	89·93	4·91	5·16	18·3	2·9
Nine Foot ...		91·40	4·78	3·82	19·1	4·7
,, ...		91·43	4·61	3·96	19·8	4·2
No. 2 Rhondda	80	87·40	5·50	7·10	15·9	1·8
No. 3 Rhondda		88·67	5·38	5·95	16·4	1·8
Four Foot ...	26	91·74	4·26	4·00	21·5	5·7
Six Foot ...	25	92·04	4·15	3·81	22·2	6·4
Nine Foot ...		91·73	4·29	3·98	21·4	5·1
,, ...		92·11	4·19	3·70	22·0	6·2

Vein.	Distance between veins in yards.	C %	H %	O & N %	C/H ratio.	Fuel-ratio.
Lower Pumpquart	about 35	93·87	3·41	2·72	27·5	25·1
Charcoal ...		94·24	3·28	2·48	28·7	17·4

On going through this Table it will be seen that approximately in about half the cases the lower the vein the higher the carbon. Of the remainder several show the reverse, while in others the carbon varies irregularly. The same result approximately is observed in the carbon-hydrogen ratio.

The general truth, however, of the rule that in any one locality the lower seams are more anthracitic than those above them is shown by the charts. A comparison of Plates 4 and 5, 5 and 6, or 6 and 7 shows that the lower seams become anthracitic in parts of the coalfield where the higher seams retain their bituminous character.

CHAPTER VII.

CLASSIFICATION OF COALS.

By W. POLLARD.

THE more recent papers on this subject are:—

C. A. Seyler, 'Chemical Classification of Coal,' *Proc. S. Wales Inst. Eng.*, Vol. XXI, p. 483, and Vol. XXII, p. 112.

'Report on the Operation of the Coal Testing Plant of the U.S. Geol. Survey,' *Professional Papers*, No. 48, Part I., p. 156.

S. W. Parr, 'The Classification of Coals,' *J. Am. Chem. Soc.*, Vol. XXVIII, 1906, p. 1425, and *Colliery Guardian*, Vol. XCII, 1906, p. 1209.

F. F. Grout, 'The Composition of Coals,' *Economic Geology*, Vol. II, 1907, p. 225.

D. B. Dowling. Report No. 1035 of the Geol. Survey Branch of the Department of Mines, Canada, p. 43.

D. White. Bul. 382, U.S. Geol. Survey, p. 8.

The Pennsylvania System (Fuel Ratio) will be found in Report M.M. of the second geological survey of Pennsylvania.

In Mr. Seyler's paper, on pp. 483–491, a good *résumé* of the older classifications is given. His own classification, though not perfect, is one of the best, if not the best, so far available. It is based on the percentage of hydrogen and carbon, calculated on the pure coal. The hydrogen determines the genus and the carbon the species. The following table, taken from 'Analyses of British Coals and Coke' (p. xv), gives the system:—

Seyler's Classification of Coal.

Carbon.	Anthracitic.	Carbonaceous.	Bituminous.			Lignitious.	
	—	—	Meta-	Ortho-	Para-	Meta-	Ortho-
	Carbon over 93·3 per cent.	93·3—91·2	91·2—89·0	89·0—87·0	87·0—84·0	84—80	80—75
Per-bituminous Genus Hydrogen over 5·8 per cent.	—	—	Per-bituminous (Per-meta-bituminous)	Per-bituminous (Per-ortho-bituminous)	Per-bituminous (Per-para-bituminous)	Per-lignitious	
Bituminous Genus Hydrogen 5·0—5·8 per cent.	—	(Pseudo-bituminous species)	Meta-bituminous	Ortho-bituminous	Para-bituminous	Lignitious. (Meta)	(Ortho)
Semi-bituminous Genus Hydrogen 4·5—5·0 per cent.	—	Semi-bituminous species (Ortho semi-bituminous)	Sub-bituminous (Sub-meta-bituminous)	Sub-bituminous (Sub-ortho-bituminous)	Sub-bituminous (Sub-para-bituminous)	Sub-lignitious (Meta)	(Ortho)
Carbonaceous Genus Hydrogen 4·0—4·5 per cent.	Semi-anthracitic species.	Carbonaceous species (Ortho-carbonaceous)	Pseudo-carbonaceous (Sub-meta-bituminous)	Pseudo-carbonaceous (Sub-ortho-bituminous)	Pseudo-carbonaceous (Sub-para-bituminous)	—	—
Anthracitic Genus Hydrogen under 4 per cent.	Ortho-anthracite	Pseudo-anthracite (Sub-carbonaceous)	Psendo-anthracite (Sub-meta-bituminous)	Pseudo-anthracite (Sub-ortho-bituminous)	Pseudo-anthracite (Sub-para-bituminous)	—	—

N.B.—The various genera are arranged in Column 1 vertically according to the hydrogen. The species in each genus are arranged horizontally according to the carbon.

The United States Geological Survey have recently dealt with methods of classification of coals, but do not mention Mr. Seyler's paper. The classification finally adopted by them is founded on the proportion of carbon to hydrogen, and the limits proposed for the different classes of coal are as follows* :—

		C/H ratio.
A	Graphite	∞ to ?
B	Anthracite	? to ?30
C	Anthracite	?30 to ?26
D	Semi-anthracite	?26 to ?23
E	Semi-bituminous	?23 to 20
F	Bituminous	20 to 17
G	Bituminous	17 to 14·4
H	Bituminous	14·4 to 12·5
I	Bituminous	12·5 to 11·2
J	Lignite	11·2 to ?9·3
K	Peat...	?9·3 to ?
L	Wood (cellulose)	7·2

The classification founded on the fuel-ratio, that is, on the relation of coke to volatile matter on coal free from water and ash, as adopted by the Pennsylvania Geological Survey, may be summarised as follows:—

	Fuel-ratio.
Anthracite	12 and over.
Semi-anthracite	8 to 12
Semi-bituminous	5 to 8
Bituminous	0 to 5

This system has been found to be unsatisfactory, except for the anthracitic and semi-anthracitic coals.

Prof. Parr has recently proposed a classification, based on the factor $VC \times \frac{100}{C}$, where VC represents the volatile carbon unassociated with hydrogen, and C the total carbon in the coal. In the bituminous and lignitious classes "inert volatile" (volatile matter less volatile carbon) is made use of for the

* This system has also been discussed by B. Renault, 'Sur quelques Micro-organismes des Combustibles fossiles.' *Bulletin de la Soc. de l'Industrie Minérale.* Sér. 3, t. xiii, 1899, and t. xiv, 1900. Also separately published.

purpose of further discrimination. In the following table the proposed limits are given:—

	$VC \times \frac{100}{C}$.	Inert Volatile.
Anthracite	4 and under	—
Semi-anthracite	4 to 8	—
Semi-bituminous	10 to 15	—
Bituminous A	20 to 32	5 to 10
B	20 to 27	10 to 15
C	32 to 44	5 to 10
D	27 to 44	10 to 15
Black Lignite	27 and over	16 to 20
Brown Lignite	27 and over	20 to 30

A further suggestion is made to express "Intrinsic Value" or "Relative Merit" of coals as fuel, assuming the true fuel-value of the coal to depend on the total carbon, available hydrogen and sulphur. The method is best shown by an example, for a coal composed of—

Carbon	78·31	per cent.
Hydrogen	4·31	,,
Sulphur	·90	,,
	83·52	

Hence the "Gross Coal Index" is $\frac{100}{\cdot 8352}$ or 120. This means that with this coal 120 lbs. will be required to make 100 lbs. of actual fuel.

Apparently the most recent classification is that of Professor Grout. It may be briefly stated to be based on fixed carbon for the anthracites to semi-bituminous, and on fixed carbon and total carbon for the bituminous and lignitious coals. Apart from a suggested diagrammatic representation of coals, the following table shows the classification proposed. All data are calculated on coal free from ash and water:—

	Fixed Carbon.	Total Carbon.
Graphite	over 99	—
Anthracite	over 93	—
Semi-anthracite	83 to 93	—
Semi-bituminous	73 to 83	—
High grade bituminous	48 to 73	82 to 88
Low grade bituminous	48 to 73	76·2 to 82
Cannel	35 to 48	76·2 to 88
Black Lignite	35 to 60	73·6 to 76·2
Brown Lignite	30 to 55	65 to 73·6
Peat and Turf	below 55	below 65
Wood	—	—

Dowling suggests the ratio of fixed carbon plus one half the

volatile matter, divided by moisture plus one half the volatile matter, the analyses being made on the air-dry sample.

White's ratio is carbon divided by oxygen plus ash.

The data on which the various classifications here mentioned are based are therefore:—

(1) Percentage of carbon and hydrogen, calculated on pure coal.
(2) The relative proportion of carbon to hydrogen—that is, the C/H ratio.
(3) The relative proportion of coke to volatile matter—that is, the fuel-ratio.
(4) Volatile carbon $\times \dfrac{100}{\text{total carbon}}$ with due consideration of "inert volatile."
(5) Fixed carbon with due consideration of total carbon in pure coal.
(6) $\dfrac{\text{Fixed carbon} + \frac{1}{2}\text{ volatile matter.}}{\text{Moisture} + \frac{1}{2}\text{ volatile matter.}}$
(7) $\dfrac{\text{C}}{\text{O} + \text{ash.}}$

Before comparing the value of these classifications for the present purpose it should be stated that the following remarks apply only from the anthracite to the bituminous or per-bituminous coals, as lignites do not occur in this coalfield, although in one or two cases coals nearing the lignitious class have been met with.

Oxygen is obtained by difference, and the occasional inaccuracies in estimation of ash have been alluded to. The volatile matter and fixed carbon estimations have also been shown to be liable to considerable errors, so none of these figures should be taken for purposes of classification if better are available. Mr. Seyler has shown also that the hydrogen and volatile matter are closely connected, so that any system in which volatile matter, and hence coke, are made use of, together with total carbon, practically amounts to classifying on carbon and hydrogen. And as carbon and hydrogen can be estimated with great accuracy, it seems more rational to use them as a basis in classification, although the proximate analysis of a coal is, in most cases, sufficient to discriminate between anthracite, semi-anthracite, and semi-bituminous coals.

The choice of classification for the present purpose therefore lies between Mr. Seyler's and the carbon-hydrogen ratio. As the object in view is to show the progressive change in character of the coal in this coal-field, and as this is most obviously shown by figures on a map, the preference falls to the C/H ratio. This ratio has the disadvantage that there is necessarily a certain amount of overlapping in the various groups and species, but it has the advantage of combining those two constituents which can be simultaneously and directly estimated with a considerable degree of accuracy, and of avoiding the necessity of recalculating on to the pure coal, when, as has been shown, considerable errors may be introduced through the oxygen having to be taken as the difference of the sum of all other constituents and 100. The only serious causes of error likely to occur in the C/H ratio are inaccuracies of moisture-determinates and the presence of carbonates or hydrous minerals in

the coal, two of which would probably be observed and the carbonate, at any rate, corrected for. The C/H limits as proposed by the United States Geological Survey would require to be modified for this coal-field, as there are, for example, many good anthracites with a C/H ratio of less than 26. The limits as marked on the maps do not designate a hard and fast line, and are not intended to imply, for instance, that all coals on one side of, say, a line marked 23 are anthracites, whilst all those on the other are semi-anthracites, &c., but are only intended to illustrate the general distribution of the different classes of coal.

In the following table the C/H limits theoretically possible for the various coals of Mr. Seyler's classification are given, also the limits observed for the various analyses here published, arranged on the same classification.

In the Tables of analyses in this Memoir all available ultimate analyses have been made use of, provided locality and vein could be identified, as it appeared fairer to do this than to select analyses. In a few cases where an ultimate analysis was not available the proximate has been given. Where there appears reason to think an analysis is doubtful or does not represent a fair sample of the vein, attention is drawn to the fact in a footnote.

Anthracitic Genus.

Species.		Possible limits of C/H ratio.	Observed limits.	No. of cases.
Ortho-anthracite		23·3 and over	23·7 and over	91
Pseudo-Anthracite	Sub-carbonaceous ...	22·8 and over	23 to 29·9*	19
	Sub-metabituminous	22·25 and over	None observed	
	Sub-orthobituminous	21·75 and over	22·08	1
	Sub-parabituminous	21·0 and over	None observed	
	Sub-metalignitious	20·0 and over		
	Sub-ortholignitious	18·75 and over		

Carbonaceous Genus.

Semi-anthracitic	20·7—24 ?	21·3 to 23·35	10
Ortho-carbonaceous	20·3—23·3	20·6 to 23·0	36
Sub-metabituminous	19·7—22·8	20·3 to 21·2	6
Sub-orthobituminous	19·3—22·2	20·31	1
Sub-parabituminous	18·7—21·75	None observed	
Sub-metalignitious	21·0—17·8		
Sub-ortholognitious	16·6—20·0		

* Two cases are not included here (Nos. 167 and 175) as the hydrogen appears abnormally low, namely 2·12 and 2·17 per cent. With the exception of No. 169, in which the percentage of hydrogen is 2·11, no other coals, even in Pembrokeshire, show less than 3·0 per cent. of hydrogen. The C/H ratios are respectively, 43·8, 43·0 and 45·1. Had they contained 3 per cent. of hydrogen the C/H ratios would have been 31·0, 31·0 and 31·7. They were communicated in MS., so it is possible a copying mistake was made, or they may have been selected for some purpose or investigation unknown.

Semi-bituminous Genus.

Species.	Possible limits of C/H ratio.	Observed lim'ts.	No. of cases.
(Anthracitic)	18·7—21·2 ?	20·2	1
Ortho-semibituminous	18·2—20·7	18·4 to 20·4	29
Sub-metabituminous	17·8—20·3	18·2 to 20·2	22
Sub-orthobituminous	17·4—19·7	17·7 to 18·8	3
Sub-parabituminous	16·8—19·3	17·8 to 18·2	3
Sub-metalignitious	16·0—18·7	None observed	
Sub-ortholignitious	15·0—17·8	16·6	1

Bituminous Genus.

Species.	Possible limits of C/H ratio.	Observed lim'ts.	No. of cases.
(Anthracitic)	16·1—19·0 ?	17·6	1
Pseudo-bituminous	15·7—18·6	17·4 to 18·2	3
Meta-bituminous	15·3—18·2	15·7 to 18·0	12
Ortho-bituminous	15·0—17·8	15·2 to 17·6	34
Para-bituminous	14·5—17·4	15·1 to 17·0	19
Meta-lignitious	13·8—16·8	15·2 to 16·7	4
Ortho-lignitious	12·9—16·0	14·6	1

Per-bituminous Genus.

Species.	Possible limits of C/H ratio.	Observed lim'ts.	No. of cases.
(Anthracitic)	13·9 ?—16·2?	None observed	
(Carbonaceous)	16·1 and less		
Per-metabituminous	15·7 and less	13·4	1
Per-orthobituminous	15·3 and less	13·4 to 14·7	5
Per-parabituminous	15·0 and less	12·9 to 14·7	4
Per-metalignitious	14·5 and less	None observed	
Per-ortholignitious	13·8 and less		

Summary of observed limits for the various Genera.

Genus	Limits	Overlap
Anthracitic genus	22 and over	
		Overlap 1·35*
Carbonaceous genus	20·3—23·35	
		Overlap ·1
Semi-bituminous genus	16·6—20·4	
		Overlap 1·6
Bituminous genus	14·6—18·2	
		Overlap ·1
Per-bituminous genus	12·9—14·7	

Out of the 321 analyses available 12 are only proximate analyses, so it is impossible to names these on Seyler's or the C/H classifications. Of the 309 where it is possible to name on these classifications, the C/H ratio shows, on the limits adopted by the United States Geological Survey:—

Anthracites	57
Semi-anthracites	57
Semi-bituminous	63
Bituminous I.	65
Bituminous II.	62
Bituminous III.	5

* For example, a coal with C/H ratio between 22 and 23·35 might belong to either the anthracitic or carbonaceous genus.

CHAPTER VIII.

EXPLANATION OF THE ISO-ANTHRACITIC CHARTS (PLATES 3 TO 8).

By A. STRAHAN.

THE object of these charts is to show areas of equal anthracitism in each seam or group of seams. The positions of the samples on the analyses of which the charts are founded are indicated by numbers corresponding to those in the table on pp. 14-30.

The degree of anthracitism of each sample is expressed by the factor representing the relation of carbon to hydrogen, *i.e.*, the C/H ratio, that factor being more suitable for the purpose than any other, for the reasons explained on p. 62. The figures in the table which give that relation range from 13 to more than 31, and for convenience the lines corresponding to the numbers 14, 17, 20, 23, 26, and 29 have been selected for illustration of the iso-anthracitic areas on the charts. The iso-anthracitic line 17, for example, is drawn through all those localities in which it is calculated that the C/H ratio would equal 17.

The space between lines 14 and 17, in any one seam, may be regarded as corresponding to the area in which that seam has the character of house-coal, but begins to assume that of steam-coal, that is belongs to the Bituminous Genus of the Table on p. 64; while that between lines 17 and 20 includes the passage into steam-coal, and steam-coal, that is the Semi-bituminous Genus of the Table. Lines 20 to 23 include steam-coal of the Carbonaceous Genus. Line 23 marks the oncoming of anthracites, and from line 24 (not shown on the charts) upwards the coals may be regarded as true anthracites.

The iso-anthracitic lines have, of course, no relation to the outcrops of the seams. In fact, a line is sometimes continued a little beyond the area in which the seam to which it relates exists, or even beyond the margin of the coal-field, where the evidence obtainable in the coal-field suffices to indicate the position it occupied before the coal-field was reduced to its present dimensions by denudation.

Plate 3.

The chart forming this plate is founded upon analyses of the lowest veins, namely, those which occur below the datum-line in Plate 2. Taken from east to west, the group includes the following seams:—

Old Coal.
Meadow Vein.
Cribbwr Vein.
Four Feet Vein (Morfa).
Four Feet Vein (Clyne Valley).
Yankee Vein.
Three Feet Vein (Clyne Valley).
Brass or Peacock Vein.
Yard Vein.
Middle Vein.
Lower Vein.
Gnapiog Vein.
Trigloin Vein.
Lower Pumpquart Vein.
Lower Trichwart Vein.
Charcoal Vein.
Little Vein.
Lower Level Vein.
Timber Vein.

The samples for analysis were obtainable from near the margin

only of the coal-field, none of the veins being accessible at present in the interior. The seams as a group lie on the same horizon, near the base of the Coal Measures, and are included in a thickness of about 500 feet of measures. The Timber Vein may correspond to the Stanllyd, which is taken as the datum-line in Plate 2.

The iso-anthracitic line 17 is determined by the analyses of the Old Coal and Meadow Vein towards the east, and by analyses of the Cribbwr Vein and the Clyne Valley coals in the South Crop. The direction in which the anthracitic character develops is foreshadowed by the analyses of both the Old and the Meadow seams, but evidence of the position of line 20 is wanting. The position of line 26 is indicated by analyses of the Brass or Peacock Vein, except that Nos. 52 and 47 with ratios of 24·03 and 23·74 do not fall into their position. On the other hand No. 168 is situated between them and shows a ratio of 29·12, which is more in accordance with expectation. The position of line 29 is proved by analyses of the Pumpquart and Triquart Veins. The Pembrokeshire analyses lie near, or on the higher side of, line 29, and correspond to, or slightly surpass, the highest stage of anthracitism reached in Carmarthenshire.

Plate 4.

This chart is founded on analyses of the vein which, in different parts of the coal-field, passes under the following names:—The Black or Rock (eastern part), Ras-las or Nine Feet (East Glamorganshire), Nine Feet or Big (North Crop on the borders of Glamorganshire and Brecknock), probably the Stanllyd and Carway Big (Carmarthenshire), and possibly the Timber Vein (Pembrokeshire). This coal-seam being more widely recognisable than most others, has been selected as the datum-line in Plate 2, and is more fully illustrated than the rest in the analyses. Analyses Nos. 167, 169 and 175 have been omitted for the reason stated on p. 63 (footnote).

The iso-anthracitic line 17 is well determined in Monmouthshire, but, so far as regards the South Crop, is founded only on an analysis of the Nine Feet at Morfa (No. 27), of the Nine Feet at Llynfi (No. 23), and of the Nine Feet at locality No. 9. It coincides approximately with the line 17 in the underlying seams (Plate 3), so far as that line has been located.

The iso-anthracitic line 20 follows a nearly parallel course, but is bent north-westwards to accommodate an analysis of the Ras-las at Dowlais (No. 22), quoted by Dr. Percy. Possibly this bend would disappear, or be modified, if further analyses east of locality 22 were available, but there is evidence of a similar bend in lines 17 and 20 in the Four Feet Seam also (Plate 5). The recent analyses show that lines 17 and 20 both extend further to the south-east than was anticipated when the first edition of this Memoir was published.

Line 23, so far as it is determined by analyses of the Nine Feet at Hirwain (No. 24) and the Nine Feet of locality 19, follows a normal course, but its westward continuation is not proved.

Line 26 is founded on a series of analyses of the Big, Nine Feet, or Stanllyd Vein of the anthracitic region. The bend in it may be due partly to experimental error in analysis, and may have little significance.

Line 29 is not reached in the Big or Stanllyd in Carmarthenshire, but its position is indicated by analysis No. 13, and it is touched at Hook (No. 198) in the Timber Vein, which may correspond to the Stanllyd.

Plate 5.

A group of veins which lies not far above the Ras-las or Nine Feet Seam in Monmouthshire includes the Elled, Big and Three Quarters. In Glamorganshire the Two Feet Nine, the Aberdare Four Feet, and the Aberdare Six Feet occupy a corresponding position with respect to the Nine Feet, but cannot be correlated individually with the Monmouthshire seams.

For the Three Quarters Seam seven analyses are available, but they give discrepant results. In Ebbw-fach, Analyses Nos. 92 and 93 show carbon-hydrogen ratios of 14·62 and 17·58; south of Blaenavon, Analyses Nos. 95 and 96 show ratios of 15·24 and 16·89; near Pontypool, Analyses Nos. 94, 97, 189 show ratios of 17·25, 17·10 and 20·51. Having regard to these discrepancies it appears to be impossible to fix the positions of the iso-anthracitic lines with sufficient precision for insertion upon the chart. The information, so far as it goes, points to an average ratio of 16·1 in Ebbw-fach, of 16·06 south of Blaenavon, and of 18·29 near Pontypool, and therefore to the ratio 17 in the Three Quarter Vein, falling approximately into line with the ratio 17 in the Aberdare Veins of Glamorganshire.

For the Big Vein we have Analysis No. 39 with a ratio of 13·43 in Ebbw-fach, and Analyses Nos. 110, 111 and 215 with ratios of 17·15, 16·81 and 16·90, near Pontypool. The Big Vein appears, therefore, to be more bituminous in any one locality than the Three Quarter Vein a few yards below.

The Aberdare group admits of more precise treatment. In the Four Feet and Six Feet Seams line 20 is fixed by a number of analyses, but the position of line 17 across the Llynfi, Garw and Ogmore Valleys can only be estimated, partly owing to the difficulty of identifying the seams. In the north-east quarter of the coal-field lines 20 and 17 in the Four Feet Seam are located by Analyses 85 and 87, but it must be noted that one analysis, No. 86, showing a carbon-hydrogen ratio of 18·93 in the Upper Four Feet of Dyffryn, falls far on the wrong side of line 20, a fact for which no explanation is forthcoming. It seems possible, however, that the hydrogen is too high, as with a percentage of 4·91 of hydrogen, a greater percentage of volatile matter than 16·23 might be expected.

For the Two Feet Nine Seam Analyses Nos. 78, 79 and 219 are available. From No. 219 it appears that line 20 in the Two Feet Nine coincides with the same line in the Aberdare Six Feet, while Nos. 78 and 79 indicate the position of line 23 and show that the approach to an anthracitic condition is less

rapid in the Two Feet Nine than in the underlying Four Feet and Six Feet Seams.

In and to the west of the Vale of Neath there occur some well-known seams on the same horizon as the Aberdare group, as shown in Plate 2. Here again the correlation of the seams individually with those of the Aberdare group is attended with doubt, though it is generally thought that the Stwrain corresponds to the Two Feet Nine Seam.

Three lines are shown in the Vale of Neath seams. They are founded on analyses of the Four Feet and of the Eighteen Feet, which lies 10 to 14 yards above the Four Feet seam. Both coals are placed on the market as anthracites, this part of the Vale of Neath being commonly regarded as lying on the margin of the anthracitic region.

The evidence furnished independently by these seams indicates that the iso-anthracitic lines trend north-westwards, as though there were a local anthracitic centre near Glyn Neath. This trend is not observable in the underlying seams (Plates 3 and 4), but is maintained in an overlying seam, the Red Vein, which is also shown on Plate 5. Though there is no doubt that further analyses would show that the lines soon resume their normal westerly trend, yet this agreement in an unusual direction in so many veins, taken as they were independently, is too pronounced to be ignored. It indicates that there are local pecularities in the distribution of the anthracitic character in certain seams or groups of seams, which are difficult to explain on the supposition that the seams were originally alike, but were subsequently anthracitised by one common cause.

The Red Vein here referred to is not to be confused with the Red Vein which corresponds to the Three Quarter Coal near Pontypool. It is recognised as a workable seam from the Dulais, a tributary of the Neath, to near Ammanford, and is regarded as an anthracite, but as approaching a steam-coal in places. The analyses, Nos. 128–135, enable the iso-anthracitic lines 23 and 26 to be fixed with some precision from Dillwyn in the Dulais valley to Cawdor, Cwmamman.

On comparing the Red Vein with those below it, it will be seen that the line 26 in the Red Vein approximately coincides with the line 23 in the Eighteen Feet Vein, and is south of the line 23 in the Cornish Vein. This indicates that the Red Vein becomes anthracitic in a region where the veins several hundred feet below it have not yet assumed that character. Here again we have an exception to the rule that the lower seams are the earlier to become anthracitic, and a further illustration of the fact that some seams betray a certain individuality in their behaviour as regards their assumption of the anthracitic character.

The position of analysis No. 124 has been inserted in this chart. The analysis gives the composition of the Lower or Welsh Vein of Cwm Clic according to Percy, and the carbon-hydrogen ratio is 25·4, which indicates that the seam is more anthracitic than the Red Vein, though it lies above it. Confirmation of this is desirable.

The Green and Drap Veins, which lie 25 and 107 yards

respectively above the Big Vein, are also shown upon this chart. In the Green Vein the positions of lines 23 and 26 are determined at localities 190 and 146, and that of line 20 in the Drap Vein at locality 145. The lines 20 in the Drap, 23 in the Green, and 25 in the Big Vein (Nos. 12, 144) approximately coincide, while line 26 in the Green lies a mile north of line 26 in the Big Vein. This, of course, means that in any one vertical section the Drap would be more bituminous than the Green and the Green than the Big, in accordance with the rule mentioned on p. 2. But, on the other hand, on comparing Plate 4 with Plate 3, we find that the line 23 in the Big or Nine Feet Vein lies six miles south of the line 23 in the Brass Vein, which is about 20 yards below, and again that the line 26 in the Big or Nine Feet lies distinctly south of the line 26 in the lower veins. This means that the Big in any one vertical section would be more anthracitic than some of the seams below it. The rule referred to is therefore not universally true.

The Green and Drap Veins correspond approximately in position to the Vale of Neath and Aberdare seams illustrated in the plate. Their composition confirms the supposition previously mentioned, that the normal trend of the iso-anthracitic lines is soon resumed west of the Vale of Neath.

Plate 6.

Plate 6 shows the iso-anthracitic lines in the seam known in different areas as the Tillery or Red Ash, the Rock-fawr, the Brithdir, the Pen-y-graig or No. 2 Rhondda. It may be compared with the chart of the Ras-las Vein in Plate 4. In both the anthracitic character develops steadily north-westwards, and, except for irregularities in the curves, which are drawn to suit certain analyses, and which might be modified if the series of analyses were more complete, there is a fairly close coincidence of lines 14, 17 and 20 in the higher seam with lines 17, 20 and 23 in the lower seam. This relation of the lines gives data for calculating the vertical rate of decrease of anthracitisation for certain localities. Thus in Monmouthshire a decrease of 3 (from 20 to 17) in the carbon-hydrogen ratio occurs in a vertical distance of 852 feet, giving a rate of 1 in 284 feet. But near locality No. 179 in the Brithdir, and locality No. 7 in the Ras-las Vein, the vertical distance is 1,350 feet, and the decrease of 3 (from 23 to 20) in that distance gives a rate of 1 in 450 feet. Again at Bronbil (locality Nos. 55 and 59) the mean of two Admiralty analyses gives a carbon-hydrogen ratio of 16·9 in the higher vein, while at Morfa (locality No. 27) the ratio is 16·2 in the Nine Feet Vein, about 2,600 feet below the Bronbil seam. Here, therefore, the higher and the lower seams are about equally bituminous, a state of affairs which probably prevails throughout the extreme southern margin of the coal-field.

The analysis of the No. 2 Rhondda Vein (No. 60) which lies nearest to the anthracitic region is quoted from Percy, who gives the seam as the Upper or Pen-y-graig Vein of Cwm Clic. It fixes one point on the line 23, but leaves us in doubt whether

that line takes the north-westward trend which is observable in the Red and other veins of Plate 5. It proves, however, that the No. 2 Rhondda seam reaches the anthracitic degree indicated by the line 23 further south than do either the Red or the Cornish Four Feet Veins, and thus furnishes another exception to the rule that the lower seams are the more anthracitic. So far as this locality is concerned the rule is generally reversed.

On Plate 6 an analysis of No. 3 Rhondda Seam also is entered. It indicates that at Penrhiw (localities Nos. 125, 196) that seam is slightly less bituminous than the Forest Vein which lies about 77 yards above it. In the Graig Seam, of which we have two analyses, the line 20 agrees closely with the line 20 in the No. 2 Rhondda Seam, although the Graig Seam lies upwards of 150 yards below the No. 2 seam. A pronounced loop towards the south-east in line 20 in the No. 2 Rhondda Vein is necessitated by analysis No. 236.

Lines 17 and 14 in the No. 2 Rhondda Vein have been redrawn to accord with the recent analyses. Line 17 in its western part is determined by analyses Nos. 55, 59, 54, 242 and 246. That it then bends sharply southwards is proved by a comparison of analyses Nos. 246 and 225, and it is to be noted that the effect of the bend is to preserve parallelism between lines 17 and 20. The return bend of line 17 to its original range is shown by analyses Nos. 204, 214 and 179. The existence of a south-eastward loop in the line in this part of the coal-field was indicated in the first edition of this Memoir, but has now been determined with greater precision by aid of the recent information.

Line 14 has been redrawn so as to pass southwards of the localities of analyses Nos. 233, 232, 224, 221 and 237. The position on the eastern margin of the coal-field is estimated from analysis No. 208.

The Hughes Vein, which is also illustrated on Plate 6, forms the lowest and most important member of a group which includes also the Slatog, Curly, and Rotten or Bodwr Veins, and has been extensively worked from near Glyn Corwg to the western end of Gower. It lies from 450 to 500 yards above the No. 2 Rhondda Seam or its local equivalent.

A comparison of the lines in the Hughes Vein with those of the No. 2 Rhondda Seam shows that the line 20 in the Hughes would, if prolonged, join line 20 in the No. 2 Rhondda, but that line 17 lies much closer to line 20 in the Hughes group than it does in the No. 2 Seam farther east. This implies that the change in character is more rapid in the west, a conclusion of which we shall obtain further evidence.

Plate 7.

The Mynyddislwyn, or Bedwas Vein, is well known as a house coal in Monmouthshire, but it occurs in detached parts only of the coal-field and the data permit no more than an approximate determination of line 14. Five analyses, Nos. 217, 73, 213, 180 and 72 are available for comparison. While they show that line 14 is not far west of the position of the same line

in No. 2 Rhondda (Plate 6), they are consistent in indicating that the Mynyddislwyn Vein becomes more bituminous in a north-westward direction.

As already explained, the Wernffraith, or Swansea Four Feet Vein, is taken to be the equivalent of the Mynyddislwyn Vein in preference to the Graigola, or Six Feet Vein, which lies 250 yards below the Four Feet. The analyses enable us to trace the line 20 for some miles. It follows the same general direction as line 20 in the Six Feet Vein, but runs into it, and crosses it to the west, the evidence for this being an analysis of Ward's Fiery Vein* (No. 104) quoted in the Admiralty Report.

That analysis gives a carbon-hydrogen ratio of 22·4, as compared with 17·9 in the Llanelly Fiery (No. 105) to the west of it, and with 19·1 in that vein (No. 101) to the east of it, although Ward's Fiery Vein lies 218 yards above the Llanelly Fiery Vein. The exact position, however, of line 20 towards the west must in any case be regarded as doubtful, inasmuch as it is founded on one analysis only.

The Graigola, or Six Feet Vein, is 270 to 350 yards above the Hughes Vein. The iso-anthracitic line 20, as determined by several analyses of the Graigola Vein, runs slightly north of the line 20 in the Hughes Vein for part of its course, and turns northwards towards the east so as to suggest the existence of a local anthracitic centre between Swansea Vale and Pontardulais. Combining this chart with that of the Aberdare Four Feet (Plate 5), we obtain the relative positions of two local anthracitic centres with a comparatively bituminous area extending northwards between them. Our information does not suffice to prove that either vein would show both centres, but it is likely that the Aberdare Four Feet would do so, for the north-westerly trend of the line 20 shown in Plate 5 is certainly replaced by a westerly or south-westerly trend a little further west.

An analysis (No. 122) of the Swansea Three Feet Vein is entered on this same chart. That vein lies 13 yards below the Six Feet, but appears to be slightly more bituminous than it, on comparison of analyses Nos. 100 and 122.

The Swansea Five Feet lies between the Four Feet and Graigola (Six Feet) Veins, and 140 yards above the latter. The analyses are limited to a small area: two from the same colliery give a carbon-hydrogen ratio of 18·8 in the Five Feet Vein (No. 74) as compared with 19·18 in the Graigola (No. 100), which gives a vertical decrease of ·38 in 140 yards in the carbon-hydrogen ratio, or 1 in about 1,000 feet. The position of line 23 is indicated by one analysis only (No. 76). The iso-anthracitic lines in the Five Feet Vein are not inserted on the plate for want of space.

The rate at which the bituminous character decreases north-

* The Fiery Vein of Llanelly is well known to correspond to the Graigola or Swansea Six Feet, but "Ward's Fiery Vein" is the name given on old plans to the Llanelly, or Box Big Vein, which corresponds to the Swansea Four Feet. The Fiery Vein of Oldcastle (Analysis No. 105), on the other hand, must be the Llanelly Fiery, inasmuch as the Llanelly Six Feet, or Box Big Vein, is "in the wind" at that colliery.

wards has been determined with great accuracy in one locality in this vein. Three sets of samples (Nos. 152–160) were collected with this object in view from three spots situated in a line running nearly north and south. Locality A (Plate 8), which yielded the samples 158, 159, and 160, was 520 yards N. 11° W. of locality B, which yielded the samples 152, 153, 154; Locality B was 1,310 yards N. 22° E. of Locality C, which yielded the samples 155, 156, 157. The results are shown in the following table and in Plate 8:—

Swansea Five Feet Vein.

	Locality A. Carbon-hydrogen ratio.	Locality B. Carbon-hydrogen ratio.	Locality C. Carbon-hydrogen ratio.
Top Coal ...	21·10	20·81	18·98
Middle Coal ...	21·15	20·89	18·77
Bottom Coal ...	20·85	20·58	18·67
Mean	21·03	20·76	18·807

These figures show that the change becomes more gradual as true anthracite is approached. Thus from C to B the rate on the mean values is one unit of the carbon-hydrogen ratio gained in 604 yards, while from B to A the rate is one unit in 1,813 yards.

The change in the part of the coal-field from which these samples (Nos. 152–160) are taken is certainly more rapid than it is in the eastern part, but data for an exact comparison are lacking, no other opportunity having occurred of obtaining samples from the same vein at a series of suitable spots.

CHAPTER IX.

Origin of Anthracite.

By A. Strahan.

Mushet was the first to attempt an explanation of the variations in the composition of Welsh coals. He pointed out that coals of different qualities are associated with similar strata, that the coal only, and not the accompanying measures, is changed, and that there is no contact of trap-rocks to account for the phenomena. He found difficulty in the supposed growth of a wide variety of plants in a limited space, and concluded that "fermentation and the degree of temperature thereby excited during the period of transition—but not that of submersion—from wood or vegetable matter into coal, may . . . furnish the most rational clue to the mystery."*

De la Beche also sketched generally the distribution of anthracite, and wrote: "Taking the coal measures of South Wales and Monmouthshire, we have a series of accumulations in which the coal beds become not only more anthracitic towards the west, but also exhibit this change in a plane which may be considered as dipping to the S.S.E. at a moderate angle, the amount of which is not yet clearly ascertained, so that in the natural section afforded we have bituminous coals in the high grounds and anthracitic coals beneath."

He found nothing to lead him to infer that there was any original difference in the coal, and attributed the anthracitisation to subsequent change. The change he believed to be due to the volatile compounds formed by decomposition having carried off relatively greater proportions of the hydrogen and oxygen than of the carbon. The view that it was due to disturbance of the strata was, in his opinion, untenable, inasmuch as the Coal Measures at Merthyr Tydfil were not more disturbed than they were at Pontypool, nor at Hirwain than they were at Pyle. The bituminous coal of Vobster, moreover, near the Mendip Hills, was far more contorted than a great proportion of the anthracitic coal of South Wales. He concludes by referring to long-continued high temperature as capable of effecting the change, and points out that if a portion of the coal-area was depressed below the other parts, and thus brought more within the influence of internal heat, decomposition in that part might have proceeded faster than in other parts. The fact that the lower beds were more anthracitic than the upper beds pointed to an influence acting from beneath and not from above.†

In 1859 Dr. J. P. Bevan‡ described the distribution of anthracitic and bituminous coals, and attributed the anthracitisation to "trap-rocks far below the surface, which have never appeared." The alteration was believed by him to have

* 'Papers on Iron and Steel,' London, 1840.

† *Memoirs of the Geol. Survey*, vol. i, pp. 217 to 221, 1846.

‡ *The Geologist*, vol. ii, p. 75, 1859.

been effected before the "Upper Measure Coals" were deposited.

Mr. Thomas Joseph,* in 1870, classified the coals according to their behaviour when burning, and showed on a map the distribution of the various classes in the eastern part of the coal-field. The gradual progress of the change from east to west was clearly recognised, but, in addition, certain faults were credited with throwing in a higher stage of anthracitisation. Mr. Joseph noted also "the regular gradation of change upwards from the lowest to the highest seams." He concluded that the coals had originally been bituminous or "dark-smoky," and had been subsequently altered, the measure for the change being marked by the progressive development of "slip cleavage" in the coal seams. The change was attributed to magnetic or galvano-magnetic action, and was considered to have been long posterior to "the occurrence of faults."

In 1877 Mr. E. T. Hardman† attributed the anthracitisation to internal heat, caused by intrusion of plutonic rocks. Prof. Galloway,‡ in 1884, classed the coals as "long-flaming *dry* coal above; the caking coals in the middle; and the *dry* steam, or anthracitic, coals at the bottom." The loss of bituminous matter was attributed to the seams having been covered by a greater thickness of strata, and consequently exposed to a higher temperature, in the anthracitic region than elsewhere.

In 1900 Mr. C. A. Seyler§ published the results of a large number of analyses and discussed in great detail the classification of coals, but did not touch upon the causes of anthracitisation.

In 1903 Mr. John Roberts,‖ in evidence given before the Royal Commission on Coal Supplies, described the distribution of bituminous, semi-bituminous, and anthracitic coals in South Wales, and estimated the area occupied by each of these classes.

Mr. David Burns¶ discusses various objections to the theories in which anthracite is supposed to have resulted from the loss of volatile matter in a bituminous coal, and comments on the fact that in going from coking coal to anthracite there is a diminution of ash. He suggests that chlorine disengaged by volcanic action combined with the hydrogen of the bituminous coal, while part of the hydrogen combined with the oxygen of the coal to form water. The free hydrochloric acid thus formed carried with it some portion of the ash as chlorides. This hypothesis is not well supported by evidence.

There was thus a general agreement that the anthracitic

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* *Trans. S. Wales Inst. Eng.*, vol. vii, p. 137, 1872.

† *Journ. Roy. Geol. Soc. Ireland*, New Series, vol. iv, p. 200, 1877.

‡ *Trans. Cardiff Nat. Soc.*, vol. xvi, p. 20, 1885; and 'Course of Lectures on Mining.' Pub. by the *S. Wales Inst. Eng.*, Cardiff, 1900.

§ *Proc. S. Wales Inst. Eng.*, vol. xxi, p. 483, 1898-1900, and vol. xxii, p. 112. See also 'Analyses of British Coals and Coke,' Introduction, *Coll. Guardian*, 1907, and 'Practical Coal Mining,' vol. i, p. 67, London, 1907.

‖ *Roy. Com. on Coal Supplies*, 2nd Rep., 1904, p. 302, and Plates 21, 22, 23.

¶ *Trans. N. of England Inst. M.E.*, vol. liv, 1904, Appendix 4, p. 1.

character had resulted from a change effected upon coals which had been originally bituminous. Three explanations of the change had been put forward, namely, that the anthracitic seams had been more deeply buried and consequently exposed to a higher temperature, that they had been altered by the neighbourhood of plutonic rocks, and lastly, that they were more affected by slip-cleavage.

To all of these theories serious objections present themselves. In the part of the coal-field where the measures are thickest, and where the seams were more deeply buried in Carboniferous times, the coals are bituminous. The same remark applies also to the covering of Secondary rocks which was subsequently spread over them. That covering was thickest in the southern and bituminous region where part of it still survives, and thinnest, if indeed it extended at all, over the northern and anthracitic part.

The trap-rocks of Pembrokeshire, which were appealed to as showing the probability of similar molten masses having penetrated under parts of the coal-field, are of pre-Carboniferous age, and therefore can have had no effect upon the Coal Measures. Moreover, coals, where whin-sills have come into contact with them in other coal-fields, have been coked and not anthracitised, while at the same time the percentage of ash has largely increased.

Slip-cleavage is not developed in anthracitic seams, nor does the theory that anthracitisation is due to the escape of volatile matter accord with the fact that the lower seams are generally the more anthracitic.

The hypothesis that the anthracitisation was due to disturbance of the strata may be put aside in consideration of the facts mentioned by De la Beche, and in view also of the distribution of anthracite in Ireland and elsewhere.

In taking the view that the differences between the anthracitic and bituminous coals in South Wales are mainly due to original differences in composition we are guided by the following considerations:—

1. While the charts confirm the general conclusions which have long been held on the distribution of the various classes of coal, they show further that some seams, or some groups of seams, possess a certain individuality. In some there are local anthracitic areas of which no evidence appears in others; the rate also at which the change to anthracite takes place differs in different seams. From a combination of these causes the rule that every seam is more anthracitic than the one above it is by no means universally true. Again, not only do certain seams differ from those above and below them, but bands in the same seam may show considerable differences in composition. These characters lend no support to a theory of the seams having been altered by one common cause acting subsequently to their deposition, such, for example, as regional metamorphism.

2. The iso-anthracitic lines show no definite connection with

the faults and disturbances. The dislocations of the strata in South Wales fall into three systems:—

(a) The nearly east-and-west disturbances which traverse Somerset, Devon, and the south of Ireland, involving within their northern margin the Vale of Glamorgan, Gower, and South Pembrokeshire.

(b) The west-south-west system which runs for the most part north of the coal-field, but branches of which traverse the Vale of Neath, the valley of the Tawe and part of the anthracitic region.

(c) The faults which range across the coal-field with directions ranging from south to south-south-east.

Of these three systems the east-and-west (a) and the west-south-west (b) are similar in their characters. Both affect broad belts of country, and are accompanied by sharp folding and over-thrusting, yet one of them (a) traverses part of the coal-field where the seams are bituminous. Though the strata may be vertical or even inverted, and sharply folded, as in Gower, yet the coal seams retain the composition proper to that part of the coal-field. That the other (b) traverses the anthracitic region appears therefore to be an accidental coincidence, though the fact that the most easterly appearance of a west-south-west disturbance in the Vale of Neath agrees in position with the on-coming of the anthracitic character, was at first sight strongly suggestive of a connection between the two.

The north-and-south faults (c) have a local effect upon the quality of the coal. The nature of the alteration is not brought out in any of the analyses quoted in this volume, the object of which is to show the normal quality of the coal, but is reported to consist in the loss of bituminous matter. The fact, however, that the iso-anthracitic lines run approximately at right angles to the faults sufficiently disproves any connection between the two. Moreover, the north-and-south faults are neither so large nor so numerous in the anthracitic parts as in some of the bituminous parts of the coal-field.

The north-and-south faults sometimes throw into opposition coals of different degrees of anthracitisation. The vertical displacement effected by these faults often amounts to 200 yards, and in exceptional cases to 800 yards. The seams now brought face to face were, therefore, originally separated by a thickness of strata equal to the throw of the fault, and differ in accordance with the general rule that the lower seams are the more anthracitic. No example has come to light of the same seam permanently changing in degree of anthracitisation on the opposite sides of a fault. It is to be inferred from these facts that the anthracitisation was prior to the faulting.

3. The anthracitisation is obviously not connected with the existing outlines of the coal-field, as determined by denudation. The anthracitic regiou appears to have lain principally outside the north-western margin of the main coal-field and to the west of it, in Pembrokeshire. Most of it has been removed by denudation, but so far as the surviving part of it enables us to judge it must have extended in a direction slightly south of west. The form of the iso-anthracitic lines suggest that it never extended eastwards beyond Monmouthshire, if so far; its

westward limit is, of course, unknown. Again, there is no connection between anthracitisation and depth from the present surface. Slight changes in the quality of the coals are observable at their outcrops, but it has not been proved that these changes are in the direction of anthracitisation. On the other hand, in the bituminous region the coals continue to be bituminous so far down as they have been followed, while in the anthracitic region the coals are anthracitic up to their outcrops.

It appears, therefore, that the coals had assumed their present character before either the outlines or the surface-configuration of the coal-field had been determined by denudation.

4. A feature in the anthracites which is brought out by the collation of analyses consists in their freedom from ash as compared with the bituminous coals. The fact is important from the point of view of the origin of anthracite, for obviously the alteration of a bituminous coal into an anthracite by the loss of bituminous matter from any cause would increase the percentage of ash.

The comparative freedom of anthracite from ash has long been known, and has been alluded to by several writers. The fact is brought out by Mushet's analyses,* and is commented on by Richardson.† Mushet's analyses are proximate only, and therefore do not yield data for the C/H ratio. On classifying them according to the fuel-ratio, we find that the average percentage of ash ranges from 3·43 in 96 analyses of bituminous coals, to 3·66 in 56 analyses of semi-bituminous, 2·61 in 25 analyses of semi-anthracite, and 2·50 in 16 analyses of anthracite. That the fuel-ratio is not the best basis of classification has already been shown (p. 60), but it suffices to distinguish roughly the four classes named. Melly‡ gives as one of the distinctive features of anthracite a low percentage of sulphur and ash. Mr. David Burns also calls special attention to the small proportion of ash in anthracite.§

By ash is meant all the incombustible residue. This includes not only any slaty films which are too thin to be picked out from the coal, but all pyrites, sulphates, and carbonates which line cracks in the coal, or are disseminated through the coal, as well as the inorganic material contained in the tissues of the plants which formed the coal. In the analyses quoted on pp. 14-30 no attempt has been made to discriminate between these different sources of ash, and it is questionable whether much would be gained by doing so. The minerals which line cracks in the coal are as likely as not to have been derived from the coal itself, and, at any rate, to separate them out before analysis would give a wrong idea of the coal as it is put on the market. The sulphur, moreover, could never be completely eliminated, as was shown by Percy in 1875.‖ The presence of

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* 'Papers on Iron and Steel,' by David Mushet. London, 1840.
† *Proc. Inst. C.E.*, vol. viii., 1849, p. 98.
‡ *Trans. N. of England Inst. M.E.*, vol. xxx, 1882, p. 175.
§ *Trans. N. of England Inst. M.E.*, vol. liv, 1904, Appendix 4, p. 1.
‖ 'Metallurgy," p. 568.

alumina in the ash would seem at first sight to prove that the ash was partly of sedimentary origin. But it has been shown to be "a characteristic and abundant constituent of the ash of many, if not all, the species of terrestrial Lycopodia; . . . that it is present in notable quantity in at least one species of tree-fern though practically absent in others; and that it occurs in insignificant amount . . . in almost every plant in which its presence has been carefully sought for."* For these reasons we will take the analyses in their original forms in considering the distribution of ash, remarking merely that the great differences of ash in some of the coals, and especially in those of the bituminous part of the coal-field, may be partly due to other causes than difference in the original composition of the coals themselves. Our conclusions must be formed on averages rather than on individual samples.

For the purposes of this inquiry we can use only those seams or groups of seams which can be traced through both the bituminous and the anthracitic areas. Of these the most prominent is the Ras-las and its supposed equivalents, for though the seams below the Ras-las persist as a group, they are not traceable individually.

The diagrams forming Plate 9 show the result of plotting a line to represent the percentage of ash existing in coal for each unit of the carbon-hydrogen ratio. The anthracites occupy approximately the left-hand half of the table, the right half showing steam- and house-coals.

In Diagram 1 all available analyses of the Ras-las Vein (or of its equivalents under other names) have been inserted. The percentages of ash shown are those actually proved in the analyses, and they are placed in position according to the proved carbon-hydrogen ratio of the coals. The diagram, therefore, in the first place illustrates the variations which have been recorded in the ash-contents of specimens of the same seam from different localities. In the second place it shows that the variation is greater towards the bituminous end than towards the anthracitic end of the scale, the range in the one case being from 0·7 to 6·2 per cent. and in the other from 2·0 to 11·60 per cent. of ash. Thirdly, it shows that the average percentage of ash increases considerably towards the bituminous end. Single exceptional analyses are responsible for most of the violent zig-zags in the line, and without doubt if a larger number was available and exceptions were merged in averages, the line would tend to become a more or less steady gradient from approximately 2·0 at the anthracitic end, to approximately 7·0 at the bituminous end of the diagram.

In Diagram 2 the seams below the Ras-las are illustrated. As no one of the seams is recognisable throughout, it became necessary to combine them and to deal with averages. All available analyses have been utilised, and the mean of those which fall between two adjoining units of the carbon-hydrogen ratio has been calculated, both as regards that ratio and the percentage of ash. Thus the means in the column 29–28 are

* A. H. Church, *Proc. Roy. Soc.*, vol. xliv, 1888, p. 127.

calculated from three analyses, namely, Nos. 303, 312, 318. The actual values obtained by the grouping of the analyses and represented on the diagram are as follows:—

Column.	Number of analyses available.	Mean C/H ratio.	Mean percentage of Ash.
Above 31... ...	1	31·50	1·0
31—30	1	30·06	·8
30—29	2	29·38	2·0
29—28	3	28·33	3·0
28—27	5	27·50	2·0
27—26	7	26·34	1·8
26—25	11	25·60	2·0
25—24	3	24·50	1·8
24—23	1	23·74	2·4
18—17	2	17·49	4·1
17—16	6	16·54	4·1
16—15	3	15·82	3·1

The diagram shows that an approximate average of 2 per cent. of ash accompanies the anthracitic state of the seams as compared with an average approximately twice as great in the bituminous state.

In Diagram 3 all available analyses of all seams* have been combined by the same method as in Diagram 2. The actual values obtained by the grouping of the analyses and represented on the diagram are as follows:—

Column.	Number of analyses available.	Mean C/H ratio.	Mean percentage of Ash.
Above 31... ...	1	31·50	1·5
31—30	2	30·48	1·1
30—29	4	29·44	1·4
29—28	8	28·49	2·48
28—27	15	27·38	2·09
27—26	21	26·44	2·91
26—25	30	25·53	2·42
25—24	14	24·49	2·40
24—23	12	23·44	3·36
23—22	14	22·49	3·43
22—21	20	21·35	4·69
21—20	29	20·50	4·47
20—19	23	19·52	4·88
19—18	22	18·59	4·57
18—17	20	17·50	5·9
17—16	32	16·58	6·02
16—15	22	15·57	6·48
15—14	8	14·53	4·35
	2	13·42	5·45
	1	12·87	2·0

* Except Nos. 167, 169 and 175, with respect to which see footnote on p. 63, and No. 309, an analysis of an unnamed seam, which appears to be abnormal.

By this combination of the analyses the effect of exceptional specimens is partly eliminated and an approximation to the true average percentage of ash is obtained, more or less close according to the number of analyses available. It will be seen that the line of means forms a fairly steady gradient from 1 per cent. at the anthracitic end, to more than 6 per cent. near the bituminous end of the scale. The column 15–14 shows a departure from the gradient, but this is partly due to one analysis (No. 123), in which the ash is exceptionally low, and partly to there being insufficient analyses available to yield a true average. Were more analyses available, the gradient would probably be still further smoothed, but even as it stands it furnishes good proof of the general rule that the percentage of ash increases with that of the bituminous constituent.

In connection with this may be taken the fact that anthracitic coals are more often "solid" than the bituminous seams. Figures for an exact comparison are not easy to obtain, but probably the comparison of a large number of average sections of seams in the two ends of the coal-field would show that the bituminous coals are more apt to be split up by partings of sedimentary material than the anthracitic. Freedom from partings and, to the eye, an almost perfect homogeneity are familiar characters in anthracitic seams. The seams themselves also are probably on the average rather thinner.

In order to ascertain what percentage of ash is contained in a mass of miscellaneous plants, and what is the nature of the alteration effected by spontaneous heat, two samples of meadow-hay from the same rick were obtained through the kindness of Messrs. Dumbelton, the one coming from near the outside, where comparatively little heating had gone on, the other from the centre of the rick, where the hay had been much heated and had become almost black. As the difference in moisture in the two samples were considerable, both were dried at 105° C. before analysis. The analyses were carried out exactly as for a coal, and the results obtained were :—

Hay affected by Spontaneous Heat.

Proximate Analysis.

	Light (outside) sample.	Dark (heated) sample.
Volatile matter	76·69	69·41
Fixed carbonaceous residue	15·70	21·31
Ash	7·61	9·28

Ultimate Analysis.

Carbon	45·23	46·82
Hydrogen	5·85	5·33
Oxygen	39·18	36·75
Nitrogen	2·13	1·82
Ash	7·61	9·28

or calculated on "ash-free" sample:—

Proximate Analysis.

	Light (outside) sample.	Dark (heated) sample.
Volatile matter	83·00	76·51
Fixed carbonaceous residue	17·00	23·49

Ultimate Analysis.

Carbon	48·96	51·61
Hydrogen	6·33	5·88
Oxygen	42·41	40·50
Nitrogen	2·30	2·01

It will be noted that the percentage of ash in the light (outside) sample is 7·61 and in the dark (heated) sample 9·28. Presumably the greater part of this ash was contained in the plants. Further, the net result of the alteration by heating was to diminish the percentage of hydrogen, oxygen, and nitrogen, and thereby increase the percentage of carbon and ash.

The foregoing statements may be summed up as follows:—

1. The seams are not all similarly anthracitic, and though each seam is generally more anthracitic than the one above it, there are many exceptions to this rule.
2. The anthracitic character was not due to faults, but existed before the faults were formed.
3. The anthracite existed as such before the coal-field was reduced by denudation to its present dimensions.
4. The percentage of ash diminishes *pari passu* with the decrease of bituminous matter.

These conclusions point to the variations in the compositions of the coals having been either original or at least of very early date. For the disturbances of the strata and the denudation which brought the coal-field to its present shape, were both in the main accomplished before Triassic times. The differences between the coals therefore already existed before any of the Secondary Rocks were laid down. Further than this the evidence derived from the distribution of anthracite does not carry us, but the remaining arguments point to the date of anthracitisation having been contemporaneous with the deposition of the Coal Measures—the strongest being that which is derived from the variation in the percentage of ash, for it is obvious that the variation cannot be due to subsequent alteration.

A further argument may be derived from the existence of pebbles or fragments of coal in some of the conglomeratic bands which occur not infrequently in the Pennant Grit of South Wales and in other coal-fields. As pointed out by M. Renault,* these coal-fragments are enclosed in bands of sandstone or argillaceous sandstone. They sometimes have the fracture of ordinary coal, with alternate bright and dull layers, and are

* 'Sur quelques Micro-organismes de Combustibles Fossiles,' *Bull. de la Soc. de l'Industrie Minérale*, sér. 3, t. xii, 1899, and t. xiv, 1900. Also separately published.

angular; or again, some have been rounded into true pebbles. They have not been deformed by the pressure of the sandstone which envelops them, nor have they shrunk since they were enveloped. It is to be inferred, therefore, that they were derived from some pre-existing coal-seam, and had already acquired their hardness and definite volume when they were buried in the sand—that is to say, they had passed into the condition of coal while the Coal Measures were still in process of deposition.

In seeking to account for an original difference in the composition of coals, it seemed worth while to inquire whether there was any connection between it and the distribution of the Coal Measures before they were curtailed by denudation. In parts of Pembrokeshire the original margin of the Coal Measures is recognisable, and though it has been removed by denudation elsewhere in South Wales, there is sufficient evidence to enable us to sketch its position approximately.

The evidence commences in the Lower Carboniferous rocks. The limestone-series is well developed in South Pembrokeshire, but dwindles away rapidly and is actually overlapped by Millstone Grit towards the north. Throughout the main coal-field the northward attenuation is no less marked, as is proved not only by a comparison of the relative thicknesses on the north and south crops, but by the poor development in the outlier of Pen Cerig-calch. Lastly, at the north-east corner of the coal-field, the whole limestone-series does not exceed 100 feet in thickness, as compared with about 500 feet further south, the upper zones having been overlapped. Traced in an east-and-west direction the thicknesses are relatively more constant, with a general tendency, however, towards expansion in the south-westerly region of the coal-field.

Assuming that the northward attenuation and overlap continued in the tract from which the Lower Carboniferous rocks have been denuded, the original margin of those rocks must have lain not far away from, and appears to have run approximately parallel to, the present margin of the coal-field. That the land-mass thus indicated in Central Wales in Carboniferous times extended across St. George's Channel into Wicklow and Wexford is highly probable, but less capable of proof, nor is there in that part of Ireland any evidence left of the overlap of the Lower by the Upper Carboniferous rocks.

The position of the original margin of the Coal Measures is more problematical, for by analogy with Pembrokeshire and other regions they may be assumed to have overlapped all the older Carboniferous rocks, and to have extended still farther north. Moreover, their margin probably occupied positions successively farther north as the subsidence which led to the deposition of so huge a mass of sediment progressed. The reasoning, however, which has been applied in the case of the underlying rocks gives a somewhat similar result.

The varying thicknesses of the Lower Coal Series, which alone of the subdivisions of the Coal Measures has a sufficiently wide distribution for our present purpose, is shown in Plate 10. The Lower Coal Series extends from the No. 2 Rhondda Seam

(or its equivalents) down to the Farewell Rock or top of the Millstone Grit. Most of the measurements are taken from shaft-sections published in Vert. Sects. of the Geological Survey, Sheets 80, 81, 83, 84, and 85. But few, if any, of the shafts have reached the Farewell Rock, and several have not been carried down to the lowest coals; in such cases an addition has been made for the estimated thickness of the unproved strata.

The smallest development is found at the east end of the coal-field, where the Lower Coal Series is 625 feet thick. The maximum increase takes place thence in a direction rather north of west, a thickness of 1,710 feet and 1,747 feet being reached in a distance of 12 miles. In the next 4 or 5 miles, however, there is a considerable drop, for in the Rhondda valleys the thickness averages about 1,430 feet. West of these valleys expansion sets in again and continues to the end of the coal-field.

The expansion, however, is more rapid along the South Crop than along the North Crop, so that a considerable difference between the two sides of the coal-field develops westward. The greater thickness of the measures of the South Crop is partly illustrated in Plate 2, in which Sections 3, 4, and 7 represent the North Crop, while Sections 2, 5, and 6 represent the South Crop. The direction of maximum thickening is somewhat west of south in the western part of the coal-field as compared with somewhat north of west in the eastern part.

Assuming as before that attenuation marks an approach to an original shore-line, this map suggests that the original margin of the Coal Measures also may have been roughly parallel to the present margin of the coal-field, but that it curved southwards at the eastern end. There appears to have been an area of least subsidence somewhere to the east of the coal-field, possibly in the neighbourhood of the post-Carboniferous anticline which brings up Silurian rocks in the Usk inlier.

A comparison of this map with the charts showing the iso-anthracitic lines lends no support to the suggestion that the distribution of anthracite had a direct and constant relation to the position of the shore-line. It is true that in the western end of the coal-field the anthracitic character increases as the thickness of measures decreases, and again in the eastern end the group of seams illustrated on Plate 5 lose bituminous matter towards the region where the measures are thinnest. But, on the other hand it is obvious that the anthracitic area is far from coinciding with the region of smallest thickness of sediments. On the contrary, the smallest thickness in the south-east and the greatest thickness in the south-west are both associated with bituminous coals.

Moreover, it is not the case in other parts of the kingdom that anthracite is associated with marginal deposits, South Staffordshire and the Forest of Wyre being notable examples. It appears, therefore, that though the anthracitic regions of South Wales and Ireland may have been nearer the original margin than much of the bituminous region, that circumstance did not necessarily lead to a difference in the coals.

But it must be remembered that coals vary in character both according to the kind of vegetable remains, and according to the parts of the plants of which they are formed. That, again, the preservation of the vegetable mass varied according to the local circumstances, such as the distance it was drifted, the depth of water in which it was submerged, the length of time that elapsed before it was buried, and the nature of the sediment which covered it.* Not only do neighbouring veins show variations due to one or other of these causes, but even parts of the same vein may differ considerably. As an extreme case, the band of cannel which is associated with the No. 3 Rhondda Seam may be mentioned.†

It is a fact, moreover, that most coals consist of laminæ of different appearance, the two kinds most commonly distinguished being 'dull coal' and 'bright coal.' Though it has not been shown, so far as we are aware, that any bituminous coal contains laminæ of true anthracite, it is certain that the dull and bright coal differ in the amount of bituminous matter they contain, and further, it is often easy to see that the dull coal is formed of fragmentary flattened stems and largely of bark, while the bright coal seldom shows organic structure.

With a view to ascertaining the difference in composition of dull and bright laminæ in a Welsh coal, a block of the Three Quarter Seam of Monmouthshire was split along some characteristic dull layers. The dull material was scraped off and readily reduced to a powder not unlike charcoal.‡ Another portion consisting wholly of bright coal was taken from the same block. The dull powder and the bright portion were then analysed with the following result:—

Proximate Analyses of Dull and Bright Layers from the Same Block of the Three Quarter Seam.

	Dull Powder.	Bright Coal.
Moisture	1·68	1·75
Volatile Matter	14·71	31·63
Fixed carbonaceous residue	77·17	63·96
Ash	6·44	2·66
Fuel ratio	5·24	2·02

* On these points reference should be made to the exhaustive researches on the origin of coal contained in the following works:—Grand 'Eury F.C., 'Flore Carbonifère du Département de la Loire et du Centre de la France,' *Paris,* 1877. Fayol, H., and others, 'Etudes sur le terrain houiller du Commentry,' *Soc. de l'Industrie minerale, St. Etienne,* 1887-93, Renault, B., 'Sur quelques Micro-organismes de Combustible Fossiles *ib.* 1899-1900, and separately published. Barrois, C., 'Le Mode de Formation de la Houille,' *Ann. Soc. Geol. du Nord,* t. xxxiii., 1904. De Lapparent, A., 'Traité de Géologie,' Ed. 5, 1906, pp. 976-990. Potonié, H., 'Die Entstehung der Steinkohle,' *Berlin,* Ed. 4, 1907.

† 'The Country around Pontypridd and Maestêg' (*Mem. Geol. Survey*), 1903, p. 43, &c.

‡ Dull coal has been described as 'Mineral Charcoal.' See analyses given in 'Coal, its History and Uses,' by Professors Green, Miall, Thorpe, Rücker and Marshall. 8vo., London, 1878.

The smaller proportion of volatile matter and the larger proportion of ash in the coal which is demonstrably formed of stems and bark is significant. In these variations between laminæ in the same seam, as well as in the variations between one seam and another, we see differences that can only be due to original deposition.

It would be anticipated that both the assemblage of plants and the conditions under which their remains were distributed would be different in the neighbourhood of dry land and in the more central parts of the coal-swamps. Generally the utmost sluggishness is evidenced in the movements of the water in which coal-seams were laid down. A certain sequence is often observable in the associated strata; sandstone, sometimes conglomeratic, is followed by shale, shale by clay, clay by coal. Each recurrence of this sequence, which may be repeated almost indefinitely, points to a gradual decrease of strength of current from that which could spread abroad sand and pebbles to the almost perfect stagnation in which plant-remains could settle to the bottom. With the slightest movement of the water the plant-remains would themselves be carried distances varying according to the time they took to settle, and would thus be sorted. Such slight movements might be expected near the margins of coal-swamps, where water was being shed off the land.

What exactly were the conditions in the physical geography, either in South Wales or in Ireland, which led to a differentiation in the material of the coal-seams there is not sufficient evidence to show. But it is a highly significant fact that in South Wales the conditions were maintained during the formation of a succession of coal-seams. As the coast-line retreated northwards, the area of anthracitic coal shifted and kept pace with it, and it is for this reason that the rule generally holds good that each seam in any one locality is less anthracitic than its predecessors. The same rule holds in the coal-field of the Pas de Calais, where it is known as the *Loi de Hilt*. There it is attributed to metamorphism subsequent to deposition, but it would appear from the facts detailed above that it is a necessary accompaniment of the formation of anthracite at successive intervals at a more or less constant distance from a retreating shore-line.

While, however, giving due weight to the evidence that the anthracitic character of the coals in part of South Wales is due to original conditions of deposition, we do not lose sight of the changes to which coals are liable in the process of time. It is a general rule that, other things being equal, coals associated with older formations approximate more closely to the anthracitic condition than those of later date. The rule is subject to many exceptions, for coal is peculiarly sensitive to local circumstances, such as intrusion of igneous material or regional metamorphism, nor can it be asserted that the dislocation of strata, and the thickness and nature of the superimposed material produce no effect. The older the formation the greater is the chance of it having undergone one or other of these vicissitudes, while, apart from this, the lapse of time alone tends to effect changes

in the character. So far as regards South Wales, it might be argued that the general rule that the older seams are the more anthracitic is due in part to one of these causes, namely, the fact that they were more deeply buried and exposed to a higher temperature than the newer seams. There is, however, no evidence that the coals in the synclines in South Wales are more anthracitic than those in the anticlines, though the difference in level sometimes amounts to several thousand feet. It would apparently be easy to over-estimate the effect due to this cause. Of all the suggested causes of alteration subsequent to deposition, none appear to have been adequate to produce more than a slight modification of the differences due to original composition.

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